Contract Report GL-95-1
September 1995

US Army Corps
of Engineers
Waterways Experiment
Station

Acoustic Emission on Cofferdam Distress Warning System and Ancillary Acoustic Emission Monitoring; Melvin Price Locks and Dam (Phase III)

by Ground Engineering, Inc.

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Prepared for Headquarters, U.S. Army Corps of Engineers
and U.S. Army Engineer District, St Louis

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by Ground Engineering, Inc.
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St. Louis, MO 63141

Final Report

Prepared for U.S. Army Corps of Engineers
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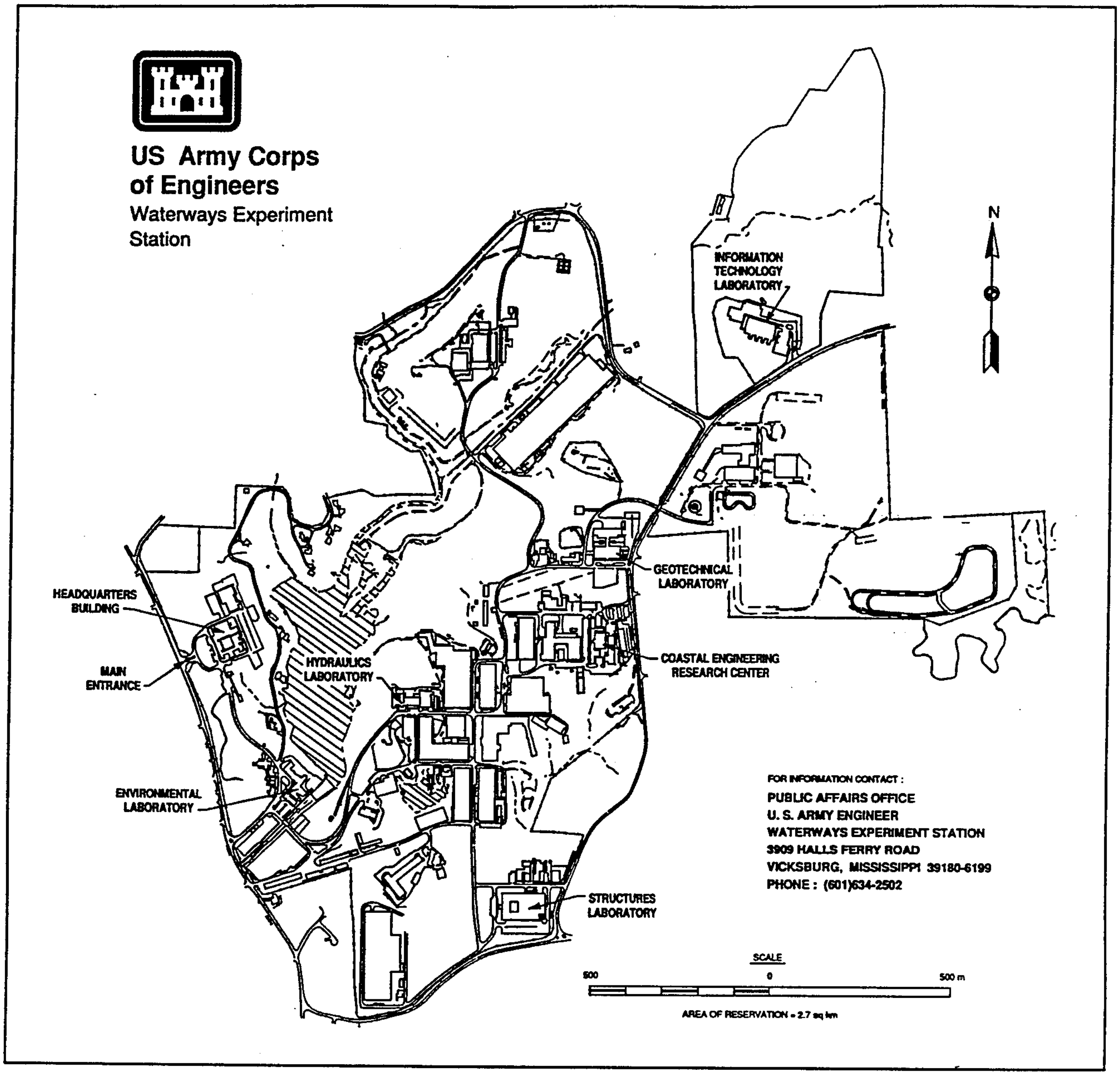

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Preface

This report was prepared by Ground Engineering, Inc., St. Louis, MO, under contract to the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS, for the U.S. Army Engineer District, St. Louis. The report was prepared under Contract No. DACW39-91-C-0005. The report summarizes the distress warning system and ancillary acoustic emission monitoring of the third-phase cofferdam at Melvin Price Lock and Dam. Mr. Earl V. Edris, Jr., P.E., Soil Mechanics Branch (SMB), Soil and Rock Mechanics Division (SRMD), Geotechnical Laboratory (GL), was the technical monitor. Mr. Pat Conroy, P.E., was the Contracting Officer's Representative, St. Louis District.

General supervision was provided by Mr. W. Milton Myers, Chief, SMB, GL, Dr. Don C. Banks, Chief, SRMD, GL, and Dr. William F. Marcuson, III, Director, GL.

During the publication of this report, Dr. Robert W. Whalin was the Director of WES. COL Bruce K. Howard, EN, was the Commander.

1 Background

1.1 Previous Contracts

Ground Engineering, Inc. (GEI) recently completed Contracts Number DACW39-86-C-0048, DACW39-89-M-2078 and DACW39-90-M-0858 entitled, "Acoustic Emission Monitoring of Cofferdam Performance; Locks and Dam 26 (Replacement) Phase II," dated September 1989, "Acoustic Emission Monitoring of Cofferdam Performance During Rewatering; Melvin Price Locks and Dam (Formerly Locks and Dam 26) Phase II," dated August 30, 1989, and "Acoustic Emission Monitoring During Extraction of Sheetpiles From Cell 72; Melvin Price Locks and Dam (Phase III)," dated May 29, 1990. Reports describing the work under these contracts were submitted in September 1989, August 1989, and May 1990, respectively. In subsequent reference to these reports, they will be identified by month and year of issue. All of the foregoing research efforts were performed by GEI for the U.S. Army Corps of Engineers, Waterways Experiment Station (WES) and were administered by the Geotechnical Laboratory, Soil Mechanics Division. Substantial assistance was afforded by the St. Louis District, Corps of Engineers (Corps).

The September 1989 Report concluded that there was a correlation between acoustic emissions (AE) generated within the unwatered cofferdam structure and differential head caused by the stage of the Mississippi River. This correlation was graphically demonstrated by extremely high AE readings as the river rose to flood level in October/November 1989.

One of several objectives of the August 1989 Report was to confirm the above correlation. Limited data was obtained during rewatering, because the elevation of the Mississippi River and consequent differential head on the cofferdam remained at low levels.

The May 1990 Report concluded that AE due to friction generated in the sheetpile interlocks during extraction were in a range consistent with those caused by the substantial hydrostatic loading on the cofferdam cells during the river flood period of October/November 1986. It also concluded that the generally equivalent magnitude of count and event rates generated by flood stage hydrostatic loading and sheet pile extraction forces suggested that sheetpile interlock shear may make a significant contribution to cofferdam stability.

1.2 Current Contract

This report is the final report prepared as a part of Contract No. DACW39-91-005 entitled "Acoustic Emission Cofferdam Distress Warning System and Ancillary Acoustic Emission Monitoring; Melvin Price Locks and Dam (Phase III)" dated December 2, 1990. The Contract consisted of five distinct tasks lettered A through E as follows: (a) Distress Warning System, (b) Barge Impact on Isolated Cell 97, (c) Monitor Cofferdam AE Emissions During Dewatering, (d) Monitor Cofferdam AE Emissions During One High Water Period, and (e) Final Report.

Task A, Distress Warning System, has been completed and will be described in this report. Task B, Barge Impact on Isolated Cell 97, was deleted from the contract. Task C, Monitor Cofferdam AE Emissions During Dewatering, has been completed and is described in a report entitled, "Report of Findings of Research Effort; Acoustic Emission Monitoring During Cofferdam Unwatering; Melvin Price Locks and Dam (Phase III) dated November 26, 1990. It is included herein as Appendix F. Task D, Monitor Cofferdam AE Emissions During One High Water Period was not performed since a high water period did not occur during the contract time frame. This report has been prepared in fulfillment of Task E, Final Report.

The Outline Scope of Work for this contract describes Task E, Final Report, as a summary of previous Task Reports and a discussion of the entire program with "emphasis on performance of distress warning system." Since the only other Task which was performed under the Contract was Task C which, as noted above, is included herein as Appendix F this report will be primarily devoted to the Distress Warning System. The greater part of the material presented herein was prepared and submitted in two interim reports entitled "Report of Distress Warning System Equipment and Installation; Acoustic Emission Cofferdam Distress Warning System and Ancillary Acoustic Emission Monitoring; Melvin Price Locks and Dam (Phase III)" dated May 30, 1991 and "First Annual Report of Distress Warning System Operation; Acoustic Emission Cofferdam Distress Warning System and Ancillary Acoustic Emission Monitoring; Melvin Price Locks and Dam (Phase III)" dated May 11, 1992. These reports were combined, amended where necessary, and expanded into this final report.

2 Objectives

2.1 Distress Warning System

The objectives of the research effort in the task were to:

a. Extend existing understanding of acoustic emission (AE) within large sheet pile cell structures to the development of a schematic design and configuration for a cofferdam Distress Warning System (DWS) capable of automatic operation for an extended period.

b. Review available technology, select appropriate system components and combine and modify them, as required.

c. Install the system on the north (upstream) leg of the Phase III cofferdam.

d. Operate the system during a brief start-up phase to ensure reliability.

e. Visit the site monthly to test the system operation and determine if it has been disturbed by construction operations.

f. Generally maintain system operation and integrity.

g. Based on the experience obtained during the foregoing elements of work determine whether the deployment and use of such systems are feasible and beneficial.

2.2 Acoustic Emission Monitoring During Cofferdam Unwatering

The objectives of the research effort undertaken in this Task and described in Appendix F were to:

a. Obtain numerous records of acoustic emissions generated in a large cellular earth-filled structure, such as the Melvin Price Locks and Dam Phase III Cofferdam, during periods of known load variation.

b. Correlate and compare these AE records with those presented in the earlier reports.

c. Correlate and compare these AE records with those obtained during the October/November 1986 high water period.

d. Develop additional understanding of acoustic emission generation and transmission.

3 Site Configuration

Melvin Price Locks and Dam has been under construction since 1979. It is located at mile 200.78 on the Upper Mississippi River about two miles downstream from the previous Locks and Dam 26 near Alton, Illinois, which has now been demolished. Phase I construction included the installation of five gate bays on the Missouri side of the river. Phase II construction included two additional gate bays and the main lock. Phase III added a second lock and completed the project. All phases of construction were accomplished "in the dry" within cellular sheet pile cofferdams. The configuration of the Phase III cofferdam is shown in Figure 1. Each cell was 63 ft in diameter and consisted of 154 PS32 interlocking sheet piles. The cells were joined by connecting arcs which consisted of 78 PS32 sheet piles. The sheet piles varied in length from 95 to 105 ft, and were embedded approximately 20 ft into the river bottom deposits. Further information and structural details concerning the project can be obtained by reference to the September 1988 report.

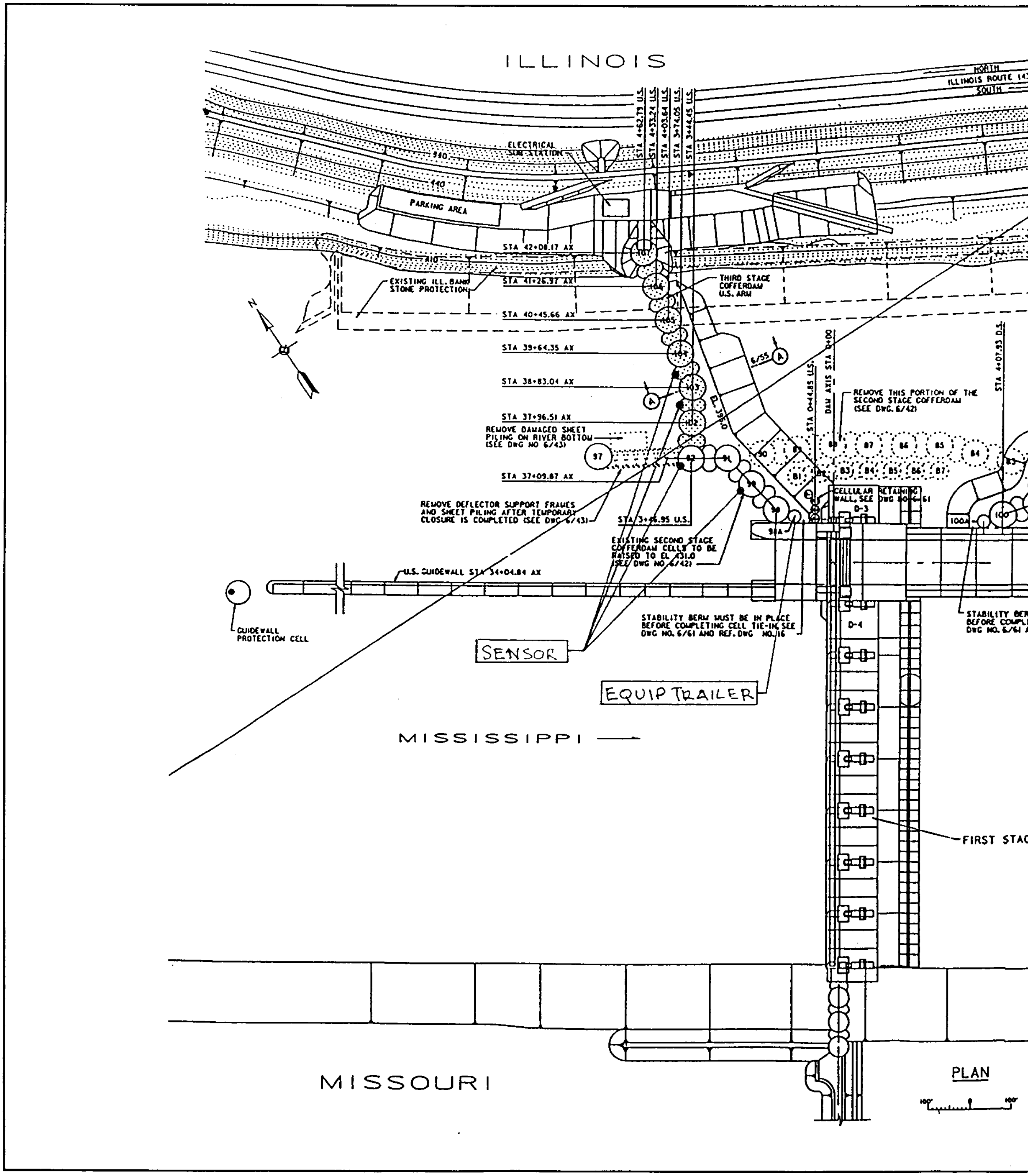
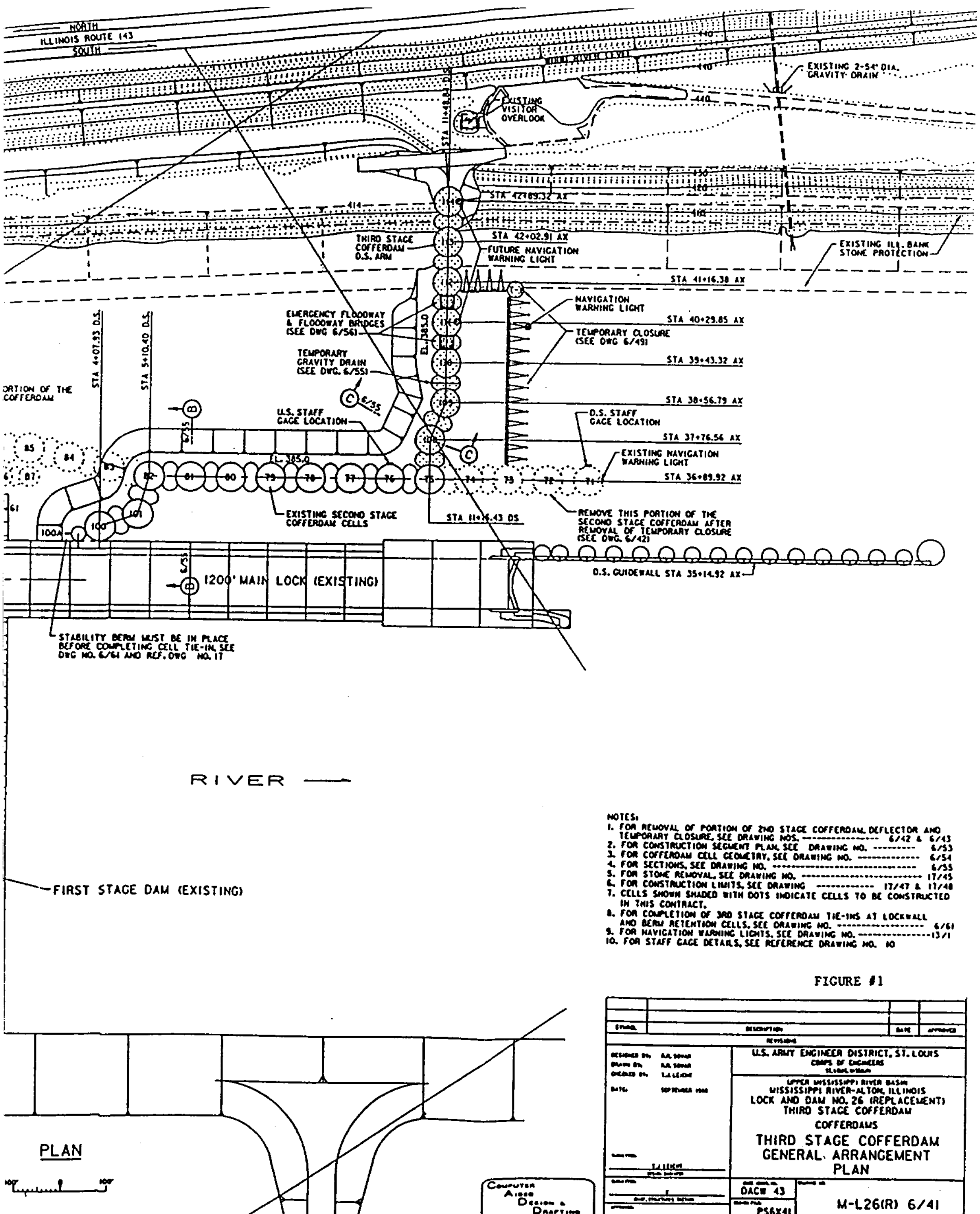


Figure 1. Site plan



NOTES:

1. FOR REMOVAL OF PORTION OF 2ND STAGE COFFERDAM, DEFLECTOR AND TEMPORARY CLOSURE, SEE DRAWING NOS. ---------------- 6/42 & 6/43
2. FOR CONSTRUCTION SEGMENT PLAN, SEE DRAWING NO. --------- 6/53
3. FOR COFFERDAM CELL GEOMETRY, SEE DRAWING NO. ------------ 6/54
4. FOR SECTIONS, SEE DRAWING NO. ------------------------------ 6/55
5. FOR STONE REMOVAL, SEE DRAWING NO. ------------------------ 17/45
6. FOR CONSTRUCTION LIMITS, SEE DRAWING ------------ 17/47 & 17/48
7. CELLS SHOWN SHADED WITH DOTS INDICATE CELLS TO BE CONSTRUCTED IN THIS CONTRACT.
8. FOR COMPLETION OF 3RD STAGE COFFERDAM TIE-INS AT LOCKWALL AND BERM RETENTION CELLS, SEE DRAWING NO. ------------------ 6/61
9. FOR NAVIGATION WARNING LIGHTS, SEE DRAWING NO. ---------------13/1
10. FOR STAFF GAGE DETAILS, SEE REFERENCE DRAWING NO. 10

FIGURE #1

U.S. ARMY ENGINEER DISTRICT, ST. LOUIS
CORPS OF ENGINEERS

UPPER MISSISSIPPI RIVER BASIN
MISSISSIPPI RIVER-ALTON, ILLINOIS
LOCK AND DAM NO. 26 (REPLACEMENT)
THIRD STAGE COFFERDAM
COFFERDAMS

THIRD STAGE COFFERDAM
GENERAL ARRANGEMENT
PLAN

DACW 43
PS6X41
M-L26(R) 6/41

4 Distress Warning System

4.1 Distress Warning System Theory

The material presented in this section is generally paraphrased from Section 9.0 of the September 1989 report.

4.1.1 General

All previous reports of AE measurements cited in Section 1.1, above, as well as investigations by others, are in agreement. They indicate a well-defined correlation between acoustic emissions and movement of deformation of a structure—in this case the sheet pile cells of a cofferdam. The AE signals are generated by the strain induced in the sheetpile/cell fill structural system by external loads which also produce stress in accordance with Hooke's Law. This correlation of AE generation with stress, and the corresponding sudden release of strain energy, lead to the conclusion that a measuring system can be devised which will monitor the performance of a cofferdam or other structure based on AE levels.

4.1.2 Hydrostatic loading, cell leakage or other damage

At large hydrostatic loading during high river levels the corresponding stresses in a cofferdam structure have generated significant AE signals. This was evidenced by the extremely high AE counts per minute recorded in the October/November 1986 flood event. Cell rupture or other damage which would significantly weaken a cell would also produce high stresses and consequent high AE counts per minute. Thus the AE emission rate can be used to gauge the magnitude and severity of stress conditions within the cofferdam cells.

4.1.3 Barge impact

At the moment of barge impact against the outer surface of a cofferdam, low frequency, high amplitude, stress waves would be propagated along the cofferdam structure. The waves would excite adjacent connecting arcs and the cells on each side of the one struck by a barge, albeit at lower signal levels

due to attenuation. The wave(s) would be propagated to adjacent connecting arcs and cells until completely damped out. Such an AE event would be spontaneously very emittive and momentarily in the very high category, probably greater than 100,000 counts per minute. The stress increase would either be accommodated in the sheetpiles, interlocks and cell fill or deformation will occur. The longer the AE signals remain at a high level, the more they indicate potential for instability and possible failure. Ordinarily, emissions due to deformation of a sand fill would tend to damp out. It is estimated that such damping would occur within approximately 15 minutes in a structure such as a cofferdam. Thus both the rate and duration of emissions can be used to evaluate the severity of barge impact.

4.2 Distress Warning System Equipment

4.2.1 System schematic

A schematic system design is given in Figure 2. It is based on the system described in Sections 9.4 and 9.5 of the September 1989 report. As shown in Figure 2 the DWS monitored four locations. Each monitoring station included a 60 KHz AE sensor, such as was used in the preceding studies listed above, and a geophone. The function of the AE sensor was to record signals generated by high river levels (large hydrostatic forces) and/or damage to a cell from rupture, leakage of cell fill, etc. The function of the geophone, which is a very low frequency sensor, was to record signals generated by an impact on a cell such as from a runaway barge. Such an event would be similar to the large low frequency movements of a seismic event for which geophones are the detection device of choice. The proposed location of the monitoring stations was on every other cell, or approximately 180 ft apart. This spacing was selected because it was believed that the physical events which would generate an alarm would propagate at least half this distance. The AE signals detected by the sensor and/or geophone were carried to the DWS Unit by connecting cables. The DWS Unit, in turn, transmitted a warning message to the Control Room of the Main Lock by telephone.

4.2.2 Equipment

The DWS was a multichannel acoustic emission monitoring system supplied by Physical Acoustics Corporation (PAC), Lawrenceville, New Jersey, see Photos 1 and 2. It was intended for use as a continuous and unattended monitoring unit. The basic system was composed of a PAC ALM-8, an 8 channel AE monitoring system; an uninterruptible power supply capable of providing up to 3.5 hr of back-up power in the event of power failure; and a security monitoring system and telephone dialer which was capable of calling four numbers sequentially and reporting an Alarm (Alert) Message. Telephone transmission was provided by a standard cellular mobile telephone.

4.2.2.1 ALM-8 Acoustic Emission Rate Monitor. The ALM-8 was a multichannel acoustic emission rate monitoring instrument manufactured by PAC. The unit was modular and utilized plug-in Eurocard type boards. It was capable of operating one to eight channels and was self-contained in a rackmount chassis. The ALM-8 monitored the AE count rate (defined as threshold crossing counts) during a user-defined period and was capable of detecting two different alarm (alert) levels on each channel. The first indicated a warning condition (high alarm) and the second a shutdown condition (high-high alarm). Only the high-high alarm was used in the DWS. In addition the channels could be configured in two different groupings. In the DWS, channels 1-4 monitored the AE sensors and channels 5-8 monitored the geophones. If any AE sensor detected a signal which was continuous for three seconds and above a pre-set threshold, Alarm (Alert) Condition 1 was activated. Similarly, if any geophone detected a continuous three second signal greater than threshold level, Alarm (Alert) Condition 2 was activated.

The Front Panel of the DWS consisted of one Display Module and eight Channel Board Modules. The Display Module was the Central processing unit for the ALM-8. It included a Count Level Display which showed threshold levels or counts per unit time received by the channel selected by the Channel Selector Switch, a Display Select Switch which selected whether counts per unit time, high alarm threshold (not used in DWS) or high-high alarm threshold was displayed. It also contained a High Group Alarm light emitting diode (LED) (not used in DWS) and a High-High Group Alarm LED, which lighted whenever a signal above the threshold was received for three consecutive count rate periods and an Alarm Reset Button used to reset the system after an alarm had been received.

The Channel Boards were numbered one through eight from right to left on the front of the ALM-8 chassis. Each Channel Board included an AE out BNC connector which permitted the AE signal received by the DWS to be transferred to other monitoring systems. It also contained high alarm (not used in DWS) and high-high alarm LEDs which lighted when a signal above the threshold was received as well as high alarm and high-high alarm calibration adjustment screws. Finally there was a System Test Push Button which served to verify the operation of each channel. See Section 4.2.3 for further discussion of system test procedures.

Each ALM-8 Channel Board had a number of internal control settings which could be varied for specific applications. These settings were established by selecting various jumper or dip switch positions. The control settings were: floating or fixed threshold, threshold level in 10 Db steps, amplified input signal or signal envelope, gain in 2 to 10 Db steps for the second and third amplifiers, channel board on which high and high-high alarm and event rate per time interval were displayed, high and high-high alarm display group, time base interval, audio alarm on or off, and energy rate divider. See Sections 4.2.2.1.1 through 4.2.2.1.4 for DWS settings used on this project.

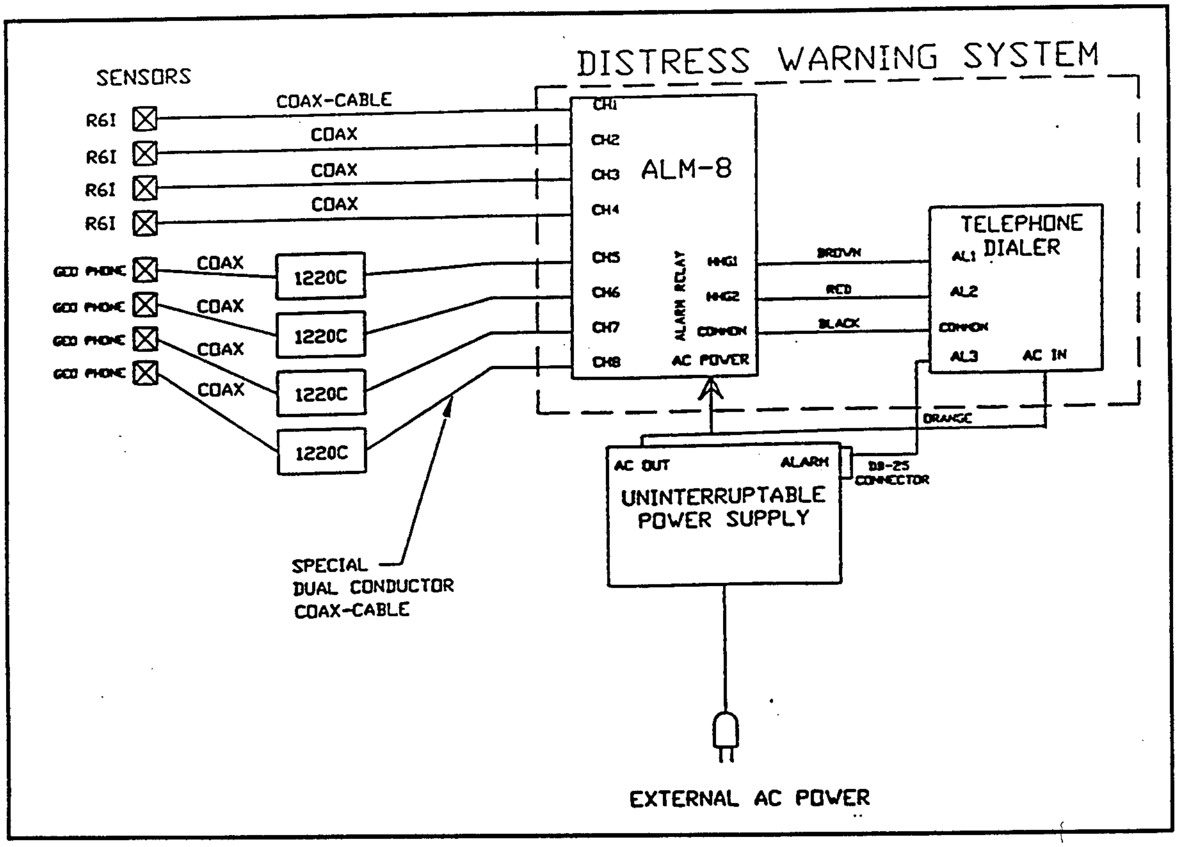


Figure 2. Distress warning system schematic design

4.2.2.1.1 ALM-8 Internal Set-Up. As indicated in Section 4.2.2.1 the ALM-8 had a number of internal set-up variables. These are listed below including the values established and used in the DWS.

4.2.2.1.2 Channel Board Set-Up. Channel Board set-up was accomplished by positioning a series of 12 jumpers and one dip switch as listed below.

a. Jumper JS1 selected the threshold set-up as "fixed" (jumper in) or "floating" (jumper out). The DWS threshold was set-up as "fixed."

b. Jumper JS2 selected the threshold level in 10 db steps. This determined the signal level above which the system began to collect data. The DWS was set-up to begin collecting data above a 90 db threshold.

c. Jumper JS3 was used for test purposes only. This jumper was permanently installed in the "on" position when the DWS was manufactured.

d. Jumper JS4 selected either the amplified input signal or the signal envelope as the output to the front panel BNC connectors. The DWS was set-up to select the "amplified input signal."

Photo # 1 - Distress Warning System (DWS)

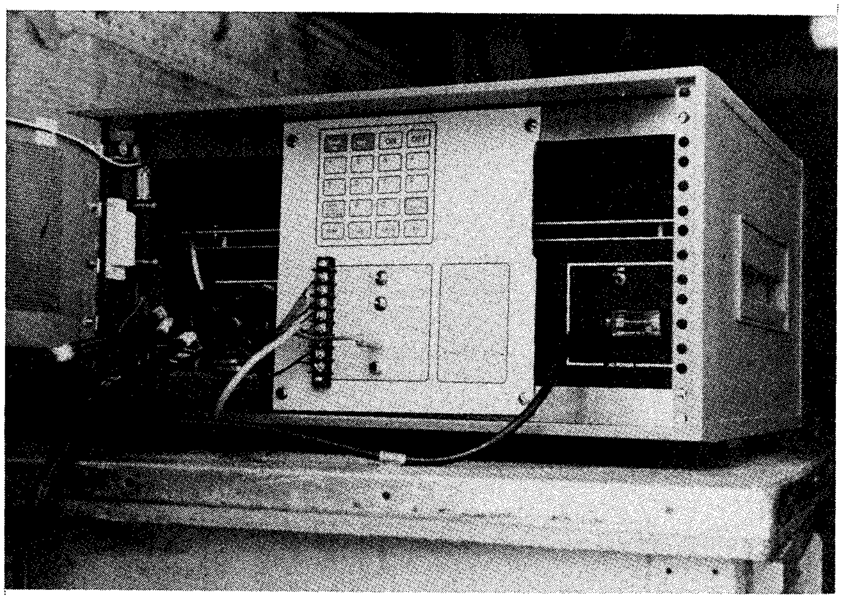


Photo #2 - DWS With Rear Door Open

Figure 3. Distress warning system installation photos (photos No. 1 through 7) (Sheet 1 of 4)

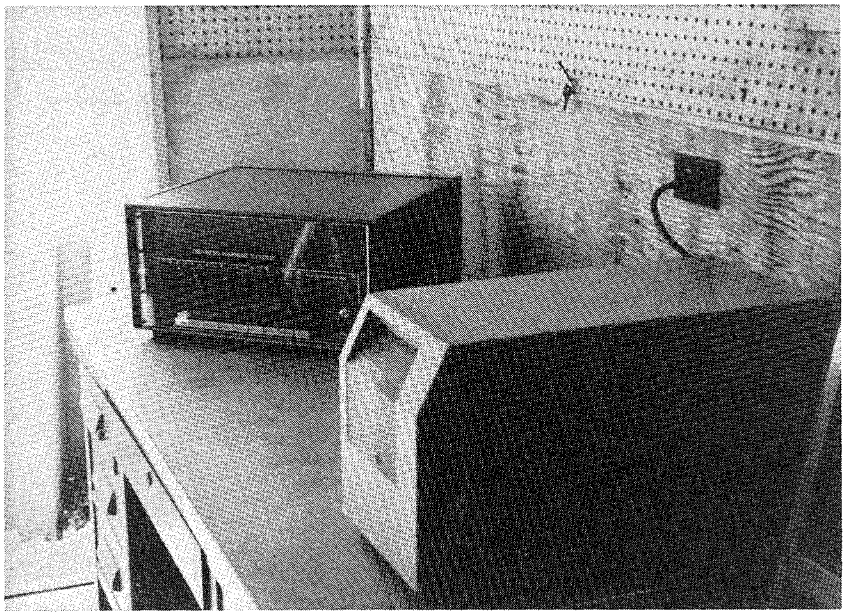


Photo #3 - DWS and Uninterruptible Power Supply

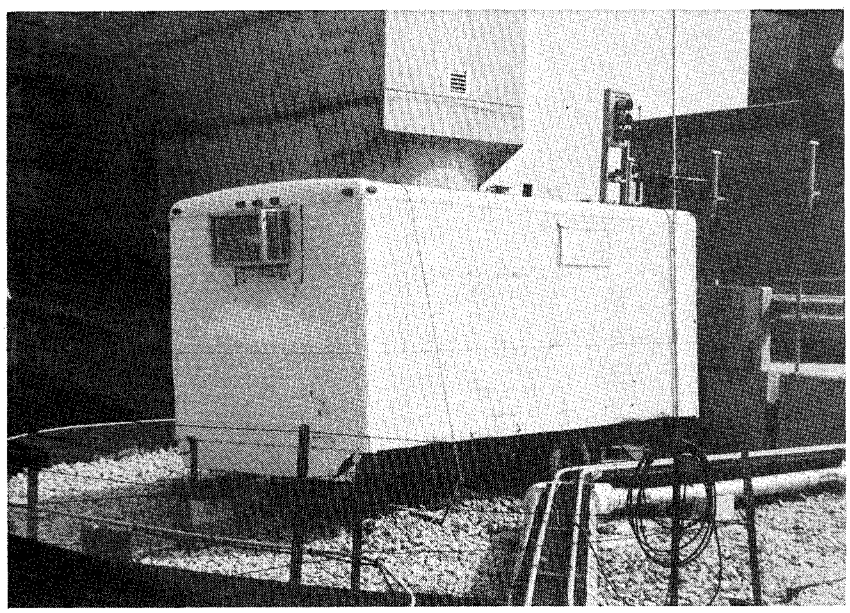


Photo #4 - Equipment Trailer

Figure 3. (Sheet 2 of 4)

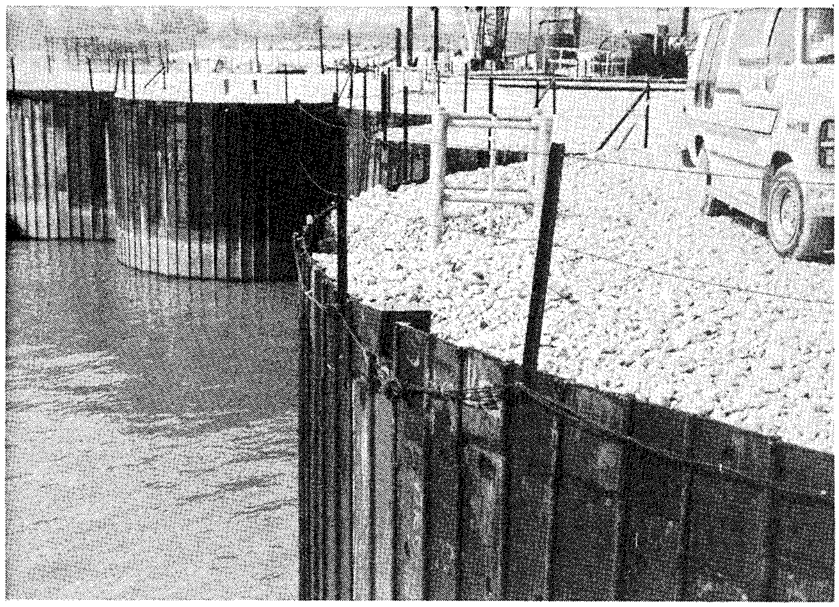


Photo #5 - Sensor Enclosure Box & Connecting Cables

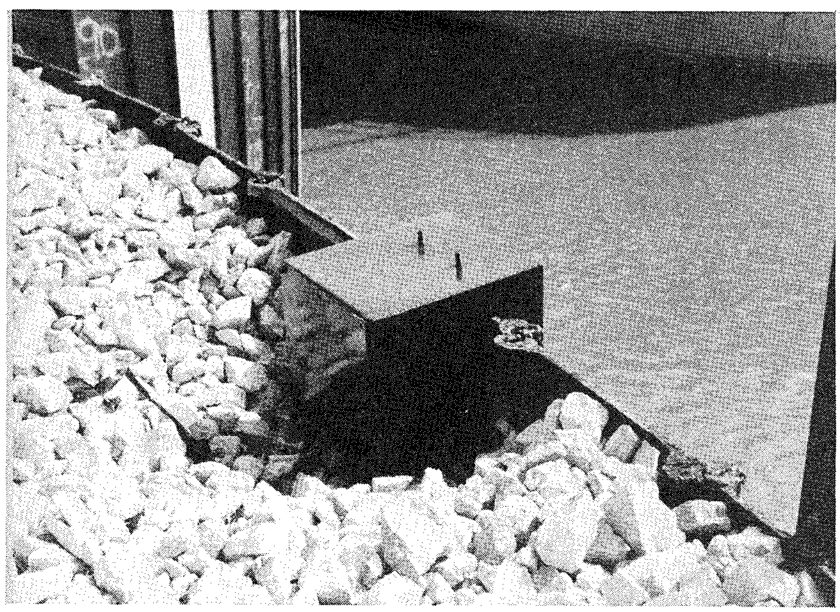


Photo #6 - Sensor Enclosure Box

Figure 3. (Sheet 3 of 4)

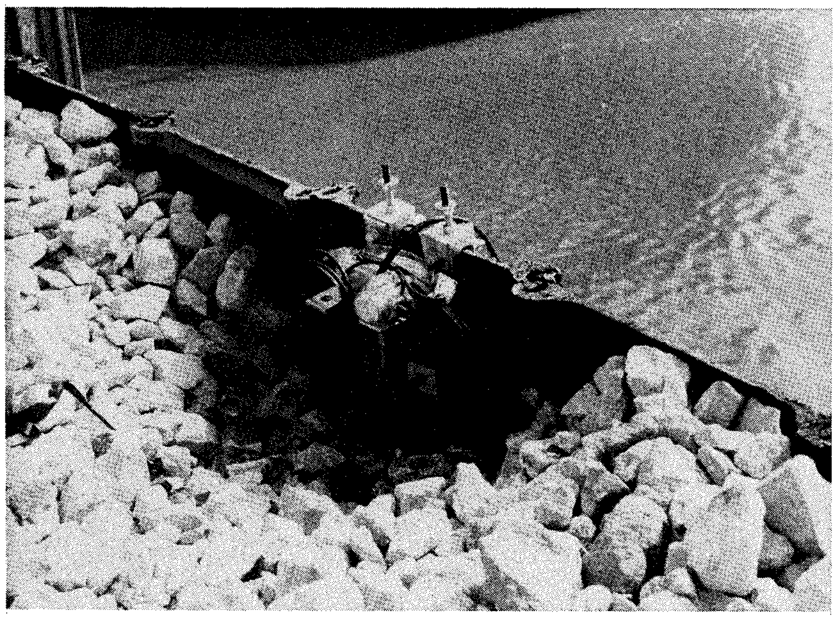


Photo #7 - AE Sensor, Geophone & Preamplifier

Figure 3. (Sheet 4 of 4)

e. Jumper JS5 selected the gain for the third amplifier in 10 db steps. The DWS was set-up for 0 db gain for AE channels 1 through 4 and 10 db gain for geophone channels 5 through 8.

f. Jumper JS6 selected the gain for the second amplifier in 10 db steps. The DWS was set-up for 0 db gain for AE channels 1 through 4 and 10 db gain for geophone channels 5 through 8.

g. Jumper JS7 selected the gain for the second amplifier in 2 db steps. The DWS was set-up for 0 db gain for both AE and geophone channels.

h. Jumper JS8 selected the high threshold output value for the channel selected by the channel selector switch.

The high threshold was not used in the DWS.

a. Jumper JS9 selected the high-high threshold output value for the channel selected by the channel selector switch. This value was displayed by the front panel read-out. Each channel board of the DWS was set-up with its channel number as its address.

b. Jumper JS10 selected the count rate output measured by the channel selected by the channel selector switch during a given time period. Each channel board of the DWS was set-up with its channel number as its address.

c. Jumper JS11 selected the high alarm output groups. These output groups were not used in the DWS.

d. Jumper JS12 selected the high-high alarm output groups. The DWS was set-up to include all AE channels in group one and all geophone channels in group two.

e. Dip switch DS1 was a four position dip switch which selected the front panel display rate divider. Positions 1 through 4 selected dividers of 1, 2, 10, and 100 respectively. The DWS was set-up for a divider of 10 for AE channels 1 through 4 and 100 for geophone channels 5 through 8.

4.2.2.1.3 Display Select Board Set-Up. Display Select Board set-up was accomplished by positioning one jumper. Jumper JS1 selected a time base interval from 0.5 to 16 sec. The DWS was set-up for a one second interval. A Channel Board LED was activated if a signal exceeded the set-up threshold for one second. A high-high alarm and Alarm (Alert) message was activated if a signal exceeded the set-up threshold for three consecutive seconds. See Section 4.3.2 for a discussion of calibration and selection of threshold values.

4.2.2.1.4 Display Board Set-Up. Display Board set-up was accomplished by positioning two jumpers.

a. Jumper JS1 selected whether the high-high audio alarm was on or off. The DWS was set-up with the audio alarm in the "off" position.

b. Jumper JS2 selected either the test or run mode. The DWS was set-up in the "run" mode.

4.2.2.2 Acoustic emission sensors, geophones, preamplifiers and connecting cables. The acoustic emission sensors utilized in the DWS were PAC Model R-6I. This sensor is a piezoelectric transducer which produces an electrical signal proportional to the amplitude of a sound or vibration detected. It had a resonant frequency of 60 KHz and included an internal preamplifier. The geophones were Model L-10A as manufactured by Mark Products, Houston, Texas. They had a resonant frequency of 30 Hz and were connected to the ALM-8 through an external preamplifier, PAC Model 1220C. The R-6I sensors were connected to the ALM-8 with RG59 coaxial cables and BNC connectors. The geophone preamplifiers were connected to the ALM-8 with a shielded twisted wire pair. The cable used in the field was a No. 9265 NEC-CL2 Twinex as supplied by PAC. It combined the coaxial cable and the twisted wire pair within a single insulated sheath. Calibration curves for the 60 KHz sensors and geophones are given in Appendix B.

4.2.2.3 Uninterruptible power supply. The Uninterruptible Power Supply (UPS) supplied as a part of the DWS was Micro-Ferrups Model ME 500VA/350W as manufactured by Best Power Technology, Necedah, Wisconsin, see Photo 3. The UPS was capable of providing consistent AC power to the DWS during both "brown-out" and "black-out" conditions. It was a stand-a-lone unit that monitored input AC power and instantly supplied power to the DWS during power fluctuations and outages. It was capable of supplying such emergency power for a period of up to 3.5 hr. In addition the UPS had alarm circuits of its own that could be monitored and reported on by telephone. These alarm circuits were not utilized in the DWS.

4.2.2.4 Security monitoring system and telephone dialer. The Security Monitoring System and Telephone Dialer (SMS) used in the DWS was a Sensapone Security Monitoring Systems Model 4000 as supplied by Phonetics, Inc., Media, Pennsylvania. It was mounted at the rear of the DWS cabinet and was accessible by opening the rear door. It automatically monitored the following ALM-8 Alarm (Alert) Conditions: (a) Alarm (Alert) Condition 1 which indicated that an Alarm (Alert) Condition had been detected on AE Channel 1, 2, 3, or 4, and (b) Alarm (Alert) Condition 2 which indicated that an Alarm (Alert) Condition had been detected on Geophone Channel 5, 6, 7, or 8.

In addition to monitoring the alarm (alert) signals generated by the ALM-8 the SMS monitored several other items as listed below.

a. AC electrical power. Monitored status of AC power.

b. Temperature. Monitored temperature between 20 and 110 deg F. Determined if it exceeded established limits.

c. Sound level. Monitored sound level. Determined it exceeded established limits.

d. Battery charge level. Monitored SMS back-up battery condition.

Alarms generated by these systems were deactivated in the DWS application. However it was not possible to eliminate the pre-programmed report on the status of these systems. See Section 4.4 for a further description of the SMS report.

All monitoring was on a continuous basis. When an Alarm (Alert) Condition occurred, the SMS announced the Alarm (Alert) condition in normal english through a microphone in the unit for 20 sec. This 20 sec announcement period was a built-in function of the SMS. It was not a part of the DWS function but could not be disabled. The SMS then proceeded to sequentially dial up to four user-programmed telephone numbers with an Alarm (Alert) Message. It stated the Alarm (Alert) Message as "Alarm Condition 1 (and/or 2) Exists" in normal english, followed by the other status reports, and waited for an acknowledgement by the person answering the telephone. If not acknowledged the SMS continued to dial the programmed numbers in sequence until an acknowledgement was received. A description of the DWS function is given in Section 4.4.

A status message of all conditions monitored could be obtained by calling the SMS at the telephone number given in Section 4.2.2.5.

The SMS had its own back-up battery. If AC power failed, it would remain on line for up to 20 hr monitoring all alarm conditions and calling the pre-programmed telephone numbers to report the power failure. However, in the DWS application the use of a cellular mobile telephone limited operation on back-up power to that provided by the UPS.

4.2.2.5 Cellular mobile telephone. Since regular fixed-wire telephone service was unavailable at the Phase III Cofferdam, a standard cellular mobile telephone transmit receive unit (TRU) was used to provide the communication capability required of the DWS. The telephone was a Model 21 as supplied by OKI Phones, Bensenville, Illinois. The telephone number was 314-570-1721.

4.2.3 System test procedure

A system test button was provided to verify the operation of each channel. It was red button on each channel board. To conduct a system test the channel select switch was set to the number of the channel to be tested and the display selector switch was set to "E." Pressing the red system test button and holding it for a period longer than the pre-set three second minimum activated the high-high group alarm LED and caused the SMS to initiate an Alarm (Alert) Message. Each channel was tested monthly while the DWS was in operation.

4.2.4 Equipment specifications

Specifications for all DWS equipment are given in Appendix A.

4.3 Distress Warning System Installation

4.3.1 Site installation

The DWS was installed on the north leg of the cofferdam. The equipment trailer was located on Cell 98A, see Figure 1, and Photo 4, and the sensors were located on cells 99, 92, and the Connecting Arcs between Cells 102-103 and 103-104. See Figure 1 and Table 1 for more specific location details. As indicated above the original plan had been to locate sensors on every other cell. This would have resulted in sensors located on Cells 99, 92, 103, and 105. However, the Construction Contractor established a sand unloading operation in the area from the Illinois shore to the Connecting Arc between Cells 104 and 105. In addition, concrete for the upstream guidewall was placed via conveyor from Cell 104. As a consequence of these construction operations the sensor locations given above were selected as the most suitable.

Table 1
Sensor Location

Cell No.	No. Shts	Fr Cell Int
99	17	West int
92	32	East int
102-103[1]	12	West int
103-104[1]	12	West int

[1] Indicates connecting arc.

At each location the AE Sensor, Geophone and Preamplifier were housed in a specially fabricated box attached to the top of the sheetpile cell wall. The boxes were painted red to make them clearly visible. See Photos 5 and 6. The AE Sensor was attached to the sheetpile with a specially fabricated magnetic holddown. Before attachment the sensor face was coated with silicone grease to provide complete contact. In addition the joint between the sensor and the sheetpile were caulked with silicone to prevent the entry of water. The Geophones were bolted to an angle which was in turn clamped to the sheetpile. See Photo 7. The Geophones have an integral level bubble and must be installed level. The clamp arrangement permitted sufficient adjustment to accomplish this. The Preamplifiers were also supported by an angle and clamp arrangement. Table 2 provides a summary of AE Sensor, Geophone, Preamplifier, and Cable Number for record purposes. It also provides

Table 2
AE Sensor, Geophone, Preamplifier, Cable and Channel Identification

Cell No.	AE Sensor	Geophone	Preamp	Cable	AE Chan	Geo Chan
99	754	101	364	65	1	5
92	755	102	363	64	2	6
102-103[1]	756	103	365	63	3	7
103-104[1]	759	104	366	62	4	8

[1] Indicates connecting arc.

a summary of ALM-8 Channels to which the respective Sensors and Geophones were connected.

The connecting cables were attached to the posts of the guard rail which followed the configuration of the sheetpiling. At each post the cable was attached to a screw clamp with a cable tie. The screw clamp was, in turn, attached to the guard rail post, see Photo 5. Waterproof red plastic tags were attached to the cables approximately every 6 to 8 ft to alert construction workers and others that the cables were not to be disturbed. The tags had the message "TEST CABLE" printed on them.

The Sensors, Geophones, and Cables were installed on April 10, 11, and 12, 1991. The ALM-8, UPS, SMS, and Cellular Phone were installed on April 15, 1991. A representative of PAC was on site from April 15 through 17, 1991 to assist with start-up of the system. The DWS was placed on line at 4:42 p.m. on April 17, 1991. Only GEI telephone numbers were programmed into the system for a start-up period that was intended to last approximately one month. During that time GEI planned to test and monitor the system for "false alarms" and other possible malfunctions.

4.3.2 Calibration

Task B of the Scope of Work was entitled "Barge Impact on Isolated Cell 97." The objective of this task was to "set low and high thresholds and calibrate the warning system." It was to be accomplished by monitoring controlled impacts of a barge on Cell 97. This task was deleted from the contract for safety reasons. As a result other methods of calibrating the DWS had to be used. After a period of research it was decided that no literature on this topic was available and that a comparative approach would be used to establish the threshold for the AE sensors and an analytical approach would be required for the geophones.

4.3.2.1 AE sensors. The calibration of the AE Sensor was based on the AE generated in the Phase II Cofferdam during the flood of October/ November 1986 as monitored by GEI and included in the September 1989

report. AE counts per minute generated in the period from September 1 through 7, 1986 as given in Figures 8.22, 8.24, 8.25, and 8.26 of that report as well as river elevations from Figure 7.3 are repeated herein in Table 3. If the low reading of 20,000 is disregarded the counts per minute during this period varied from 60,000 to 400,000. Since the function of the AE sensors in the DWS is to warn of high water and/or damage to a cell due to rupture, leakage of cell fill, etc. it was judged that a threshold value of 200,000 counts per minute would be a reasonable minimum. Counts per minute above this threshold would almost certainly indicate that forces of major magnitude were present.

Table 3
River Elevation Versus AE Counts Per Minute October 1986

Date October 1986	River Elevation Figure 7.3	Cell 80 Figure 8.22	Cell 87 Figure 8.25	Cell 91 Figure 8.26
10-01-86	416.8	--	--	--
10-02-86	417.2	170,000	20,000	--
10-03-86	419.2	120,000	--	100,000
10-04-86	421.3	400,000	--	60,000
10-05-86	424.2	80,000	--	100,000
10-06-86	425.9	240,000	180,000	130,000
10-07-86	427.2	380,000	150,000	180,000

Note: All values scaled from September 1989 report.

At the same time the threshold was high enough to reject false warnings. Since the ALM-8 records AE counts per second and the count rate divider setup was 10, the threshold setting for AE channels 1 through 4 was 200,000/ (60 × 10) = 333. Each AE channel board was set to this threshold value by use of the high-high alarm adjustment screw.

4.3.2.2 Geophones. The procedure originally proposed to establish a threshold for geophone signals in counts per minute was as follows: (1) calculate geophone output for collision of a barge with cofferdam at a speed of ten miles per hour, (2) proceed with Contract Task B Barge Impact on Isolated Cell 97 at a minimum speed, (3) estimate actual speed of collision, (4) record geophone counts per minute for actual barge impact, (5) calculate geophone output for impact of barge with cofferdam at actual speed of collision, (6) use a comparative analysis of the ratio of the two calculated collision results to develop the ratio of the actual collision geophone signals to be expected for the barge impact at 10 miles per hour. Thus $B_{actual} : B_{10\ mph} = G_{actual} : G_{10\ mph}$ where B is geophone output in microvolts and G is a geophone signal in counts per minute.

A theoretical derivation of geophone output in microvolts resulting from a barge impact at ten miles per hour ($B_{10\ mph}$) is included herein as Appendix C. It was prepare by Jozef M. Descour, Research Associate, and reviewed by Dr. Russel J. Miller, Ph.D., Research Professor, both of the Colorado School of Mines. It was also reviewed by Dr. Adrian A. Pollock, Ph.D. of PAC.

Since actual controlled barge impact had been deleted from the Contract, the above calibration procedure could not be carried to completion and other methods had to be utilized to develop a threshold value for the geophones. This value was established as 120,000 counts per minute based on the best judgment of GEI and PAC.

Since the count rate divider for geophone channel 5 through 8 were set up as 100, the threshold for these channels was set to a value of 120,000/ (60 × 100) = 20.

4.4 Distress Warning System Function

The DWS was designed to function as follows. Once on line, it would monitor the upstream (north) leg of the Phase III Cofferdam and report AE or geophone signals above pre-set thresholds. When such a signal was received, the SMS would be activated. The SMS would dial the pre-programmed telephone number of the Lock Control Room, yyy-yyyy and give the following message:

> "Hello, this is telephone number xxx-xxxx. ALERT CONDITION 1 (and/or 2) EXISTS. Hello, this is telephone number xxx-xxxx. ALERT CONDITION 1 (and/or 2) EXISTS. Hello, this is telephone number xxx-xxxx. ALERT CONDITION 1 (and/or 2) EXISTS. The time is (*announces time of day*). The temperature is (*announces temperature in Equipment Trailer*). The electricity is On. Sound level OK. ALERT CONDITION 1 (and/or 2) EXISTS. Battery condition OK. Listen to the sound level for 15 sec (*15 sec pause*). Indicate you have received warning message (*5 sec pause during which call should be acknowledged by pressing 5,5,5 on push button telephone*). Warning message received by telephone number yyy-yyyy."

If the warning telephone call is not acknowledged the SMS would proceed to the following message.

> "Indicate you have received warning message. Dial telephone number xxx-xxxx within 60 sec (*60 sec pause during which receipt of warning telephone call should be acknowledged by dialing xxx-xxxx*). Warning message received by telephone number yyy-yyyy."

If the warning telephone call was not acknowledge the SMS would redial the same telephone number (yyy-yyyy) and continue to do so until the call was acknowledged as described above.

Personnel in the Lock Control Room would have an instruction sheet which described the Alarm (Alert) message and acknowledgement procedure. They would be further instructed to investigate to determine if the cofferdam has been struck or if any other problem existed. If so, they were to call the Corps of Engineers Area Engineer or his representative at their home telephone during non-working hours. It was assumed that any problem which developed during working hours would be detected by personnel on the site and the Alarm (Alert) Message would be redundant.

4.5 Distress Warning System Start-up

4.5.1 General

Installation of the Distress Warning System was completed on April 17, 1991. At that time the system was programmed to call GEI to report any and all Distress Warning Messages in order to ensure that the DWS would not generate "false alarm warning messages." This procedure was intended to continue for a two to four week test period prior to re-programming the system to call the Lock Control Room. At the same time GEI was to test the DWS Status Report function by calling the system periodically to obtain a report of system conditions.

4.5.2 Status report messages

During the first three to four weeks of start-up operations, difficulty was experienced in completing calls to obtain a DWS Status Report. A recorded telephone company message was often received indicating that there was no answer at the DWS number or that the cellular phone station had left the area. The latter status was, of course, not possible. A representative of Physical Acoustics Corporation (PAC), the supplier of the equipment, visited the site on May 8 and May 14, 1991. During the first visit he replaced the Telephone Message Generator, but to no avail. During the second visit the Telephone Dialer Transmit-Receive Unit was replaced. This corrected the difficulty.

4.5.3 False alarm warning messages

At 7:18 a.m. on May 9, 1991 the first of seven "Alert Condition 2 Exists" false alarm warning messages was received. This message indicated that one or more of the four geophone channels had been activated. Contact with the Corps of Engineers Area Office (Area Office) and Alberici-Eby Joint Venture, the construction contractor, did not reveal any site activity which might have

triggered the false alarm warning messages. Similar false alarm warning messages generated by geophone channels five through eight continued to be received at irregular intervals between May 9 and September 10, 1991 as shown in Table 4. No false alarm warning messages were activated by AE

Table 4
False Alarm Warning Message Summary

False Alarm Message		Sensor Type		Geophone CH Reset	
Date	Time	AE Sensor	Geophone	Date	Time
05-09-91	07:18 a.m.	--	Yes	05-14-91	04:00[1] p.m.
05-14-91	10:00[1] p.m.	--	Yes	05-22-91	11:15 a.m.
05-22-91	02:06 p.m.	--	Yes	06-01-91	12:00 NN
06-14-91	10:22 p.m.	--	Yes	06-26-91	04:00[1] p.m.
06-16-91	09:26 a.m.	See text		06-26-91	04:00[1] p.m.
09-10-91	11:00[1] a.m.	--	Yes	09-10-91	11:30 a.m.
09-10-91	12:06 p.m.	--	Yes	11-12-91	05:30 p.m.

[1] Indicates approximate time.

channels one through four. The message received at 9:26 a.m. on June 16, 1991 deserves further discussion. At that time, the DWS reported "Alert Condition 2 Exists"; "Alert Condition 3 Exists." The Alert Condition 2 Exists message was apparently another false alarm. However, the Alert Condition 3 Exists message was legitimate. It indicated a power failure. Upon consultation with the Area Office it was determined that all power had been shut down at the site for extensive maintenance from approximately 6 a.m. until approximately 2:30 p.m. on that day. The Alert Condition 3 Exists message received at 9:26 a.m. was transmitted after the three and one-half hour battery storage capacity of the DWS Uninterruptible Power Supply was exhausted. An "Alert Condition OK" message was received at 2:27 p.m. indicating that power had been restored to the project. An "Alert Condition 2 Exists" message was received at 2:41 p.m. indicating that the original false alarm which had triggered one of the geophone channels still existed. Subsequently, the Alert Condition 3 Exists warning message was disabled since this information concerning electrical power was not significant to Lock Control Room personnel.

After the geophone channels had been re-set on November 12, 1991, no further false alarm warning messages were received for the duration of DWS monitoring, a period of approximately nine months.

4.5.4 Channel board failure during start-up period

Each of the eight channels of the DWS was controlled by a uniquely addressed electronic board which activated its response to incoming AE signals. The electronic address of each board can be re-set by adjusting jumper positions on the board to conform to the number of the chassis slot into which the board is placed. As described previously, if the incoming AE signals were above a pre-set threshold, a distress warning message was generated. During the ten month period between the April 17, 1991 DWS start-up and the date February 4, 1992 DWS Activation, a number of boards failed and had to be returned to PAC for rework, as shown in Table 5. Board failure was identified and determined by a "drop hammer test" (DH test) in which a hammer with specific energy as used in the modified Proctor test (ASTM D 1557) for "Moisture/Density Relationship of Soil" was dropped on a sheet pile adjacent to a sensor station and the resultant AE signals monitored at the DWS. In general, five hammer blows were delivered and recorded for each channel. If, after confirming cable continuity and integrity with a test board known to be functional, no signal was detected at the DWS, the board was considered to have failed. As a practical matter, the DH test was performed at least twice. If no signal was recorded on either DH test, the board was considered non-functional. Both AE and geophone boards failed during the start-up period. Four of six boards returned to PAC for servicing during the start-up period failed again upon re-installation after they had been reworked. As a result of the foregoing record, a PAC service technician spent December 20, 1991 at the site. During this time he made an exhaustive check of and serviced the system. He did not find any specific item to which the frequent channel board failures could be attributed.

Table 5
Channel Boards Returned for Rework

Fail Date	AE	Geophone	Date Ret	Date Ins
06-26-91	--	Yes	07-26-91	07-30-91
07-30-91	--	Yes	08-27-91	09-10-91
10-15-91	Yes	Yes	11-05-91	11-12-91
11-12-91	Yes	--	12-20-91	12-20-91
12-20-91	Yes	--	01-20-92	02-04-92
02-04-92	--	Yes (2)	02-20-92	03-29-92

Notes:
1. Column headings as shown below:
2. Fail Date = date of board failure.
3. Date Ret = date board sent to PAC.
4. Date Ins = date board re-installed.

4.5.5 Cable severance during start-up period

Careful attention was given to the physical location of the cables connecting the DWS to the AE and geophone sensors. Meetings were held with

representatives of both the Area Office and Alberici-Eby in order to coordinate this effort and select locations that would be least subject to interference from or with construction operations. Despite these attempts, two of the four cables were severed during a rock fill operation on September 20, 1991.

The damage to the system connecting cables occurred adjacent to connecting arc 92/102. While they were severed, channels 3, 4, 7, and 8 were not operational. An attempt was made to splice the identified locations of the severed cables during the week of November 11, 1991 by GEI staff. Only the channel 7 cable was successfully spliced and restored. Subsequently, the PAC service technician referred to above was onsite on December 20, 1991; while there he spliced all of the identified breaks in the four cables. After splicing the cables connecting channels 4 and 8 to the DWS functioned satisfactorily when tested with the standard DH test. The channel 3 and 7 cables did not transmit signals when tested leading to the conclusion that there was at least one other break in each of these cables which was not discernible by visual inspection.

A verbal status report was given to and the situation was thoroughly discussed with WES and the Corps. The alternatives were: (1) replace the cable connecting the channel 3/7 sensors to the DWS, or (2) abandon the channel 3/7 sensor station. Since the channel 3/7 sensor station was located at the juncture of the west side of the upstream guide wall and the cofferdam, it was considered unlikely that it would suffer an impact from a runaway barge. Therefore, the remaining sensor stations would be sufficient to provide a distress warning signal at all locations likely to be affected by a barge impact. Consequently if was agreed that the channel 3/7 sensor station would be discontinued.

4.6 Distress Warning System Activation

After completion of the system check by a PAC service technician on December 20, 1990, the DWS was considered sufficiently reliable to activate its intended warning function by re-programming the dial-out telephone number to that of the Lock Control Room. In anticipation of this event, GEI had prepared an instruction sheet to be posted in the control room. This sheet provided a general description of the DWS warning message and described how to respond to it. The information was reviewed and modified by the Corps until all concerned were satisfied with the result. It is included as Appendix D.

A meeting was arranged for December 30, 1991 to effect the activation of the DWS. Scheduling complications forced the postponement of this meeting to January 23, 1992 and then to February 4, 1992. On that date, the Acting Lockmaster and three control room personnel were instructed on the function of the DWS dial-out distress warning message and how to respond to it. In addition, they visited the DWS equipment trailer and were given a key to it as well as instructions on how to turn the system off in the event that persistent

false alarm warning messages were received. The dial-out telephone number was re-programmed to that of the Lock Control Room, completing the start-up phase of the contract.

4.7 Distress Warning System Operation After Activation

In the period after official activation of the system it continued to be beset by Channel Board failures and cable discontinuities as described in the following.

4.7.1 Channel board failure

DH testing of the DWS on February 4, 1992 after system activation resulted in the failure of the two Channel Boards that had been returned after rework and installed on that date. They were again returned to PAC and reinstalled on March 29, 1992. No further channel board failures occurred for the duration of the project. See Table 5 for a summary of channel board failures.

4.7.2 Cable discontinuities

The channel 8 cable which had functioned properly during the DH test conducted on December 20, 1992 failed to record AE signals in a DH test conducted on February 4, 1992 after activation of the system.

A local audio technician was engaged to attempt the repair of the channel 8 cable. He visited the site on March 1 and 8, 1992. During these site visits a second break in each of the channel 3 and 8 cables was discovered and repaired. These breaks were at cell 102. As a part of the visual inspection of the cables carried out on March 1, 1992, sensor boxes 3/7 and 4/8 were unbolted and opened. When open, it was discovered that cables 3, 7, and 8 had been disconnected. The cause of this situation was unclear. Either the PAC technician who visited the site on December 20, 1991 failed to re-connect the cables prior to closing the sensor boxes or they were tampered with by vandals. Neither explanation is convincing. The PAC technician was an experienced repairman and it would be most unlikely for him to leave cables unconnected, when his final actions before leaving the site would be to confirm that all lines were intact and recording at the DWS. In fact, channel 8 did record on final testing before his departure. On the other hand, the sensor boxes were secured with two bolts that required a wrench to open. If the boxes were opened by an unauthorized person, it is also unlikely that the covers would be replaced and rebolted after the cables were disconnected. The reason for this disconnection will probably remain a mystery. In any event, barring a repetition, establishment of the cause was not germane to the operation of the DWS.

At the conclusion of the above repairs, all channels were operational in a DH test performed on March 8, 1992. However, since two geophone boards returned for rework had not been repaired, only channels 1 through 6 were in service. The next DH test was performed on March 29, 1992. During that test, channel 4 did not record AE signals. GEI staff returned to the site on April 5, 1992 with the audio technician to determine the reason for the failure of channel 4 to record. Tests indicated that the connecting cable was "open"; that is, non-conductive. A thorough visual inspection, including checking the condition of previous splices, failed to reveal any further breaks in the cable. As a result, only seven DWS channels (1, 2, 3, 5, 6, 7, and 8) were operational on that date.

During the regular monthly system inspection conducted on May 28, 1992 only channels 1, 5, and 6 recorded signals during a DH test. Since all channels except channel 4 had been operational on the previous inspection conducted on March 29, 1992 it appeared that there were further undetected discontinuities in the channel 2, 3, 4, 7, and 8 cables. Repair of these cables was attempted on July 19, 1992. On that date all cables were visually inspected. No further severed or damaged areas were detected. A DH test on that date confirmed that only channels 1, 5, and 6 were operational. This situation was reported to WES and the Corps and a series of alternate courses of action were suggested as follows:

a. Investigate the availability of rental equipment that could locate the break(s) non destructively.

b. Detach the cables from the guardrail posts, stretch them out on the cofferdam surface, visually check for broken or damaged areas and attempt to repair them. This appeared to be the least effective alternative since the cables had been carefully inspected in place several times.

c. Check all sensors to determine if they were operational. This would entail opening each sensor box, substituting a working sensor and conducting a Drop Hammer Test to determine if the channel recorded AE signals.

d. Replace 150 to 200 ft of connecting cable in the vicinity of the accidental cable severance which occurred on September 20, 1992. If successful this procedure would correct the discontinuities in cables 3, 4, 7, and 8. It would not correct the problem with channel 2. It would result in seven of eight channels in workable condition.

e. Replace all cables. This would be the most costly of all options.

f. Do nothing. Since DWS cofferdam monitoring was to end on December 31, 1992 the system could continue to function for the remaining five and one half months with only channels 1, 5, and 6 operational. the two operational geophone (channel 5 and 6) were west of the upstream guidewall and in strategic position to detect a barge impact.

Cable repair was further discussed with the Technical Support Group of a cable manufacturer. It was their opinion that water had probably gotten under the coaxial cable jacket and saturated the foam insulation. Such saturated insulation would rapidly deteriorate and destroy the ability of the cable to function. In their opinion the best solution to the problem would be complete replacement of all cables. This was also reported to WES and the Corps with the recommendation that either alternate e., replace all cables, or f., do nothing, be adopted.

A regular monthly system inspection was conducted on August 17, 1992. A DH test conducted upon arrival at the site indicated that none of the eight channels recorded AE signals. It had been expected that channels 2, 3, 4, 7. and 8 would be inoperative since they had been so for several months. However channels 1, 5, and 6 had functioned during the July inspection and system check. A visual inspection revealed that all cables had been severed at approximately the midpoint of cell 91. The break was not clean but showed evidence of crushing and tearing as if caused by construction equipment. Once again the situation was reported to both WES and the Corps. As a result of this latest problem it appeared that possible alternate procedures were reduced to attempting to splice cables 1, 5, and 6 or replacing all cables.

4.8 Distress Warning System Termination of Operation

After due consideration of all of the foregoing WES decided to cease DWS monitoring. The rationale for this decision was as given below:

a. The probability that cables 1, 5, and 6 could be successfully spliced was low to moderate based on previous experience.

b. The system had only three operational channels and therefore was not functioning at full capacity.

c. The DWS monitoring program had been scheduled to end on December 31, 1992 in any event.

d. The research and technical information phase of the design, development and installation of the DWS was complete.

e. The fourteen months of system operation were sufficient to enable an evaluation of it to be made.

As a result of the above decision the DWS, sensor stations, connecting cables and all other equipment were removed from the project site on August 30, 1992. As a part of such removal an attempt was made to salvage those portions of the connecting cables which appeared undamaged. As they were detached from the cofferdam guard rail it was discovered that they had

been severed or crushed in ten to twelve other places. Only the first several hundred feet of each cable was salvageable. The remainder was damaged to the point that it was no longer usable. The additional damage discovered during removal was probably the cause of the failure of channels 2, 3, 4, 7, and 8. The fact that the damaged areas were not discovered during in place visual inspection of the cables is attributable to the difficulty of viewing the entire circumference of each cable in the group.

4.9 Distress Warning System Operational Channels

Due to re-set time after false alarm warning messages, the failure of channel boards, the severance of sensor cables by construction operations, and the disconnection of cables 3, 7, and 8 described above, the number of serviceable channels at any time varied. These are summarized in Table 6.

Table 6
Channel Operational Dates

Date		Operating Channels		
From	To	AE	Geophone	No. Days
04-17-91	05-09-91	1,2,3,4	5,6,7,8	22
05-09-91	05-14-91	1,2,3,4	-,-,-,-	5
05-14-91	05-14-91	1,2,3,4	5,6,7,8	1
05-14-91	05-22-91	1,2,3,4	-,-,-,-	7
05-22-91	05-22-91	1,2,3,4	5,6,7,8	1
05-22-91	06-01-91	1,2,3,4	-,-,-,-	9
06-01-91	06-14-91	1,2,3,4	5,6,7,8	13
06-14-91	06-26-91	1,2,3,4	-,-,-,-	12
06-26-91	09-10-91	1,2,3,4	5,-,7,8	76
09-10-91	09-10-91	-,2,3,4	5,6,7,8	1
09-10-91	09-20-91	-,2,3,4	-,-,-,-	9
09-20-91	11-12-91	-,2,-,-	-,-,-,-	53
11-12-91	12-20-91	-,2,-,-	5,6,7,-	38
12-20-91	02-04-92	1,2,-,4	5,6,-,8	46
02-04-92	03-08-92	1,2,-,4	5,6,-,-	33
03-08-92	03-29-92	1,2,3,4	5,6,-,-	21
03-29-92	05-28-92	1,2,3,-	5,6,7,8	60
05-28-92	08-17-92	1,-,-,-	5,6,-,-	50

This table shows that all four AE channels were in service for 167 days; three channels were in operation for 149 days; and only one channel was in service for 141 days. This last included a 91-day period from September 20

to December 20, 1991, awaiting the arrival of a PAC service technician to check the entire system.

The record for the geophone channels shows 95 days during which no channel was in operation. This period is an accumulation of days between false alarm warning messages and system reset, plus a 53-day period from September 20 to November 12, 1992 awaiting the arrival of the PAC service technician. In addition, there were 98 days when all four channels were in service; 160 days during which three channels were operational; and 104 days when two channels were in operation.

Overall the AE channels functioned 1,255 out of a possible 1,828 channel-days or 69 percent of the time. The geophone channels were operational for 1,080 of a possible 1,828 channel-days or 59 percent of the time.

4.10 Distress Warning System Discussion

The design, development, equipment selection, fabrication, installation, start-up and operation of the DWS achieved mixed results. The first five of these elements, that is, design through installation were carried out in an orderly and timely manner. At their conclusion, it appeared that the last two elements, start-up and operation, would proceed on schedule as planned. However, as described below, the system was beset by a number of significant problems including equipment malfunction, equipment replacement and repair delay, and damage resulting from construction activities. These difficulties ultimately resulted in termination of the Project approximately four months prior to its scheduled end. The following sections discuss the above in greater detail.

4.10.1 Design, development, equipment selection, fabrication, and installation

The conceptual design of the DWS was developed and presented in Sections 9.4 and 9.5 of the September 1989 report. That effort was carried further under the current contract and is described in Section 4.2 and 4.3, above. The design concept was expanded and refined and suitable off-the-shelf equipment selected and acquired. The various elements of the system were modified as required and assembled into an operational unit which had the theoretical capacity to fulfill DWS system requirements. System installation was carefully planned and efficiently accomplished. After completion it appeared that the project was on schedule and the DWS ready to fulfill its intended function.

4.10.2 Equipment malfunction

Although the DWS was a semi-experimental system it was composed of several known and tested subsystems and was expected to be reliable in operation. As described in Section 4.2 these subsystems consisted of: a PAC ALM-8 Acoustic Emission Rate Monitor; associated AE sensors, geophones, preamplifiers and connecting cables; a Phonetics, Inc. Model 4000 Security Monitoring System and Telephone Dialer, and OKI Phones Model 21 Cellular Mobile Telephone transmit-receive unit and a Best Power Technology Micro-Ferrups Model 500VA/350W Uninterruptible Power Supply. Each of these subsystems was reputed to be extremely reliable. This was especially true of the ALM-8 which is widely used to monitor various industrial processing operations which are unattended over long periods of time.

Despite the anticipated reliability of the DWS the system malfunctioned in several ways as follows: (a) early difficulty in obtaining call-in status reports; (b) transmission of false alarm warning messages and; (c) channel board failures.

The difficulty in obtaining call-in status reports was resolved relatively quickly by replacing the mobile telephone transmit-receive unit in a routine maintenance operation. The reason for the transmission of false alarm warning messages over a four month period was not clearly identified although it was apparently associated with channel board failure. Nor was the cause of channel board failures which occurred with distressing regularity over an eight month period. See Section 4.10.3 for a discussion of channel board failure.

4.10.3 Channel board failure

Eight channel boards were returned for testing and rework during the first eight months of project activity. No one board or chassis slot failed consistently nor was any equipment or site specific reason identified as a probable cause of channel board failure. Six of the eight boards returned for rework failed to record AE signals upon their reinstallation in the DWS. After the boards were reworked PAC was unable to provide an explanation for their failure. Since the boards had been tested by the PAC engineering department and found satisfactory before their return to GEI this appeared to indicate that the cause of failure was a malfunction within the DWS chassis systems. The PAC technician sent to the site on December 20, 1991 failed to detect and/or correct any such problem. In fact, a reworked channel board which he brought with him failed upon reinstallation. It is not clear, therefore, whether channel board failure can be expected of other DWS systems similar to this one or if this system had a unique undetected fault. In any event regular drop hammer testing to assure that channel boards are operable appears to be indicated. The need for this procedure was not envisioned in the DWS design.

4.10.4 Start-up delay

After installation of the DWS was completed on April 17, 1991 a start-up period of approximately one month was considered reasonable. As recounted above the period was actually eight months not counting the period during which the activation meeting was postponed. This can be attributed to several reasons; (a) equipment malfunction resulting in false alarm warning messages, see Table 4; (b) channel board failure and excessive time to return and rework boards, see Table 5, and (c) a significant delay caused by the September 20, 1991 construction incident which severed the channel 3/7 and 4/8 cables. While delay caused by equipment malfunction and channel board failure was understandable it was not expected or excusable. Delay caused by construction interference was unanticipated but provided valuable insight into the design and installation of future DWS systems.

4.10.5 Channel board return and rework delay

A significant amount of time was lost returning failed channel boards for rework and in the actual rework itself. In order to remedy this situation it is recommended that any future DWS installation include several spare boards which can be installed to provide continuity of service during board rework. Obviously a better solution would be more reliability in system and channel board fabrication and performance.

4.10.6 Cable damage from construction activities

As described in Section 4.5.5 two connecting cables were severed by construction activities in September 1991. As a result channels 3, 4, 7, and 8 were out of service for varying periods of time over the next year as efforts were made to splice and resplice the severed cables. It appeared at that time as if splices which performed satisfactorily immediately after completion were failing after a short time as evidenced by one or more of the affected channels failing to record in a later DH test. As described in Section 4.7.2 a second cable severance was discovered during a regular monthly inspection on August 17, 1992. In this incident all four cables were completely severed at cell 91. This severance apparently occurred in the period between July 19 and August 17, 1992 since a complete visual inspection of the cables had been made on the July date. In addition a substantial number of additional cut or damaged areas of individual cables were discovered as the cables were being removed after termination of DWS monitoring as described in Section 4.8. Based on the foregoing record it can be concluded that construction activities damaged the DWS connecting cables more often than had been originally believed. It also appears that the continuing failure of various channels to function from September 1991 through August 1992 were not all attributable to the September 1991 construction accident but were the result of a larger number of unobserved and/or unreported construction incidents in which the cables were torn, damaged and/or cut.

Based on the above information it can be concluded that the connecting cables attached to the cofferdam guard rail and draped on the exterior face of the cells were quite vulnerable to damage by construction activities. Several other cable locations were considered at the time of DWS installation but rejected for various reasons as follows:

a. Attached to the exterior cofferdam guard rail but laid on the rock fill along the inside face of the cell. It was believed that this exposed location would subject the cables to damage from personnel and vehicular traffic.

b. Enclosed in thin wall electrical conduit and attached to the exterior cofferdam guard rail. This cable deployment system would have provided greater protection, although it is not certain it would have been substantial enough to withstand the construction damage to which the cables were subjected. In any event it was rejected due to the increased cost of such an installation.

c. Enclosed in thin wall electrical conduit attached to the interior cofferdam guard rail and conveyed to the sensor stations in a direct burial trench across the cofferdam surface. This system would have provided the greatest amount of protection to the connecting cables. It was also rejected due to cost.

4.11 Distress Warning System Operational Assessment

Although the DWS had a number of early operational problems they were substantially resolved in the first eight months of operation. After that time all further failures of the system to record during monthly testing were attributable to unreported and undetected damage to the system connecting cables. If the cables had been intact the DWS would have been in operational condition and ready to report cofferdam distress. Even with damage to five of eight cables the system had three operable channels which were adequate to provide the warning anticipated in the DWS design concept. Since there were not high water events, barge impacts or other incidents of cofferdam distress effectiveness of the DWS calibration techniques were untested. Other than that the system functioned as envisioned.

4.12 Distress Warning System Monthly Status Reports

In accordance with the contract, status reports were prepared each month. These reports from December 1990 through September 1992 are included as "Appendix E." They provide a general running account of activities during the contract period. The report for September 1991 gave an incorrect location

for the cable damage referred to in Section 4.5.5 and the report for April 1992 listed channel 8 instead of channel 4 as not operational. These discrepancies have been corrected on the copies included in Appendix E.

5 Conclusions and Recommendations

5.1 Distress Warning System

As a result of the experience gained in the design, development, deployment, and operation of the DWS described herein the following conclusions and recommendations are presented:

a. The general objective of Task A of this project to translate the concept of a DWS into a workable system was accomplished. The concept outlined in Section 9.4 and 9.5 of the September 1989 report was developed into an operational system using off-the-shelf equipment and technology. The system was installed on the north leg of the Phase III cofferdam and functioned essentially unattended for a period of sixteen months. Although a number of anticipated difficulties arose during that period it can be concluded that a distress warning system is a practical, feasible and effective application of AE theory and that the system described herein can serve as a prototype for future similar applications.

b. The DWS adequately demonstrated that continuous monitoring of acoustic emissions by automated and computerized equipment which detects signals through strategically located sensors can ensure early warning of structural distress. Such warning can be an important and useful approach to the maintenance of structural integrity of cofferdams and other maritime structures subject to such events as a severe barge impact. The method can also be used to give timely warning against rapid deterioration of granular filled cells and similar structures that may have sustained moderate initial damage or experience high deformation stresses due to large differential water levels and attendant hydrostatic forces.

c. In this semi-experimental application of the concept the reliability of the DWS was disappointing as evidenced by recurrent false alarm warning messages and channel board failures during the early months of the project. In future system acquisition it is recommended that the supplier be required to conduct and document a prior performance test of the equipment for a period of reasonable length, say 60 days. Although

the false alarm warning messages and channel board failures were significant early concerns they were resolved within eight months after DWS installation. The major system problems for the remaining eight months were caused by damage to the connecting cables from construction activities. See paragraph e. below.

d. In order to reduce or eliminate the time when a DWS may be partially out of service it is recommended that several spare channel boards be purchased and maintained in readiness as replacements for boards requiring return to the supplier for rework.

e. The DWS site installation was inadequate to prevent cable damage and/or severance incidents resulting from construction activities. It is recommended that consideration be given to placing the sensor cables in protective conduit in future installations. The most secure installation on a cofferdam would appear to be in conduit attached to the interior face of the cell wall and in a trench under the cell fill to sensor stations at the exterior cell wall. Although more costly than the installation used on this project, this set-up would provide greater protection to the cables and significantly improved reliability of the system.

f. Calibration of DWS systems remains an area which requires additional experimental investigation. The alarm threshold calibration methods used on this project were logically derived but not tested by an actual physical impact or large hydrostatic cell loading. The data which could be obtained from monitoring a controlled barge impact on a marine structure would be an important addition to AE theory. It is recommended that such a test or tests be carried out on a future project. In addition, data obtained during a high water event would have been valuable in the calibration of future DWS systems. Since such an event did not occur during this project it is recommended that future DWS installations record and document corresponding AE levels in order to establish alarm thresholds. Such recording can be accomplished by equipment similar to the PAC ATLAS 7016/3000 unit used in the study described in the September 1989 report. The necessary AE signal is available from the DWS front panel output BNC connectors described in Section 4.2.2.1.

g. Once the start-up problems of false alarm warning messages and channel board failure were resolved those channels of the DWS whose cables were undamaged generally performed satisfactorily. However since no barge impact or high water loading on the cells occurred to test the planned function of the system it is not possible to reach a conclusion concerning the total effectiveness of an installation of this type.

5.2 Acoustic Emission Monitoring During Cofferdam Unwatering

In general, the objectives of this study were achieved. They are described as follows: continuous records were obtained of acoustic emissions generated within a large cellular sheetpile/earth structure, such as the Melvin Price Locks and Dam Phase III Cofferdam, during periods of known load variation against the cells; these records were correlated and compared with those presented in previous reports; and the data obtained provided additional understanding of acoustic emission generation and transmission through the sheetpiles and interlocks.

Unfortunately, the relatively small differential head developed during this study permitted only limited comparison of AE with the exceptional data obtained during the October/November 1986 period, when considerably greater hydrostatic loading was applied to the cells.

Two practical conclusions may be drawn as a result of the work described above; (1) it is essential to carefully plan and install an unattended continuously recording AE station in order to minimize interference from construction activities; this should include one sensor not connected to the sheetpiles that is exclusively assigned to "pick up" AE generated by extraneous (construction) noises; and (2) to arrange for automatic alternative temporary power as total reliance upon the main project electrical power network can result in the interruption of equipment functioning and loss of data acquisition.

5.3 Overall Conclusions

Since only two of the four tasks comprising the project were completed the overall objective of extending the knowledge and understanding of acoustic emission generation in large earth structures such as cofferdams was only partially fulfilled.

a. Contract Task A, Distress Warning System, was performed successfully as described in Section 4.0, above, and a number of significant conclusions and recommendations derived from it will facilitate the future development and deployment of similar systems. In that sense the effort did advance the general knowledge and understanding of AE and its practical application.

b. The deletion of Task B, Barge Impact on Isolated Cell 97 prevented the opportunity to obtain significant AE data which, as far as can be determined, is unavailable in any published form.

c. The small differential head in effect during Task C, Monitor Cofferdam AE Emissions During Dewatering, prevented any meaningful

comparison with exceptional data recorded during the October/November 1986 high water levels of the Mississippi River.

d. Similarly, because a high water event did not occur during this project, the consequent omittance of Task D, Monitor Cofferdam Emissions During One High Water Period prevented an opportunity to obtain reliable data confirming the very high levels of AE recorded during the river flood levels of October/November 1986.

e. Since the 1986 data was obtained from a portable AE recording system and was not continuous it was a fragmentary picture of the AE generation caused by the large hydrostatic forces engendered by that flood. It had been hoped that Tasks C and D of this contract would serve to develop data which would confirm that recorded in 1986 and extend the understanding of AE generated in large earth structures. Unfortunately that did not occur.

Overall, it can be concluded that for reasons beyond the control of GEI only Task A, Distress Warning System was accomplished satisfactorily while the remaining project tasks did not accomplish their objectives or were aborted for various reasons.

Appendix A
Equipment Specifications

APPENDIX A

EQUIPMENT SPECIFICATIONS

Equipment Specifications

ALM-8 Acoustic Emission Rate Monitor

Model:	ALM-8
Height:	10.125 inches
Width:	19.75 inches
Depth:	18 inches
Weight:	40 lbs.
AC Voltage Input:	115 AC volts ± 10%
AC Power (max):	80 watts max.
Temperature:	0 - 100 degrees F
AE INPUT:	
AE Channels (1 - 4):	- 50 ohms terminated to accept input from external PAC 1220A Series pre-amplifiers. - 28 volts on same center conductor to power external PAC pre-amplifier.
Geophone Channels (5 - 8)	- Differential input connector. One conductor carries the AE signal into the System from the pre-amplifier. The second conductor carries 28 volt power to the 1220B pre-amplifier.
A E FILTERING:	
AE Channels (1 - 4)	- pluggable filter inside the ALM-8. Filter value 20 - 100 KHz. This is for use with A3, R6 or R6I PAC sensors.
Geophone Channels (5 - 8)	- pluggable filter inside the ALM-8. Filter value is 20 KHz Low pass. This is for use with the geophones.
AE AMPLIFICATION (ALL):	0 - 50 dB in 2 dB steps (set internally on ALM-8 cards).
AE FEATURE PARAMETER:	AE Count created via threshold crossings is the key parameter of the system. The AE count parameter is summed during the count rate period and displayed for each channel as selected by the frontal panel.

Equipment Specifications

ALM-8 Acoustic Emission Rate Monitor

(continued)

COUNT RATE PERIOD:	User selectable rates of .5, 1, 2, 4, 8, 16 seconds. Adjustment is on the display select board.
GROUP SET-UP:	2 physical alarm groups have been set up in the Distress Warning System . Group 1 consists of the 4 AE channels and group 2 consists of the 4 geophone channels.

Equipment Specifications

Uninterruptible Power Supply

Model:	ME 500VA/350W
Height:	12 inches
Width:	10 inches
Depth:	21 inches
Weight:	85 lbs.
AC Voltage Input:	120 VAC
Temperature:	0 - 105 degrees F
Relative Humidity:	0 - 95% without condensation
Input/Output Voltage:	120
Input Service:	10 amps
Input Plugs:	5-15P
Maximum Output Current in amps:	4.2
Output Receptacles:	5-15R
Quantity:	4
Efficiency on AC Line:	85%
BTU/hour On Line	210
Audible Noise (dB)	41
Runtime: (in minutes)	
Full Load:	22
Half Load:	53
Weight (lbs.)	
Without battery:	45
With battery:	70

Equipment Specifications

Acoustic Emission Sensors, Geophones and Pre-amplifiers

AE Sensors:

Model R6I

Resonant Frequency 60 KHz

Peak Sensitivity > -30 dB

Pre-amplifier Gain 40 dB

Noise < 1.5 MV RMS

Operating Temperature -45c to 75c

Dynamic Range > 85 dB

Power Losses < 3dB for 750 ft. RG 58 Cable

Geophones:

Model L-10A

Standard Frequency Range, Hz	10-30		
Frequency Tolerance	$\pm 5\%$		
Standard Coil Resistance, Ohms	138/215/374		
Resistance Tolerance, %	5	5	6.5

Maximum Distortion @ 0.7 in/s @ 12 Hz or Resonance: 0.2%

Transduction Constant, V/in/S $\pm 10\%$: $0.041\sqrt{Rc}$

Open Circuit Damping, $\pm 10\%$: $\frac{4.289}{f}$

Coil Current Damping: $\frac{16.93\ Rc}{f(Rc + Rs)}$

Suspended Mass, Grams: 12.20

Power Sensitivity, mW/in/s: 1.67

Case-to-Coil, Motion, in.p-p	0.080
Basic Unit Diameter, in.	1.25
Basic Unit Height, in.	1.4
Basic Unit Weight, oz.	5.0

Equipment Specifications
(continued)

Acoustic Emission Sensors, Geophones and Pre-amplifiers

<u>Preamplifier</u>

Model 1220 C

Gain:	40 or 60 dB (Switch selectable)
Bandpass:	User selectable from 10 KHz to 1.2 MHz
Input:	Single or differential selectable
Input Impedance:	10 K ohms in parallel with 15 pF
Output Voltage:	20 Vpp into 50 ohms
Dynamic Range:	90 dB
CMRR (500 KHz):	55 dB
Noise (RMS RTI):	< 2 uV
Power Requirements:	1220A,C - +28 VDC
1220B - /-15 VDC	
DC Standby Current:	25 mA

Specifications apply at 25 C +/-5 C
Preamplifier will operate from 0 C to 50 C

Dimensions:	3 cm x 6 cm x 11 cm
Weight:	0.25 Kg

EQUIPMENT SPECIFICATIONS

Security Monitoring System and Telephone Dialer

Model:	4000
Height:	10.250 inches
Width:	10.375 "
Depth:	4.125 "
Weight:	12 lbs.
AC Voltage Input:	110 V AC 60 Hz
Wall Transformer:	UL Class 2, 6 ft. cord
Voltage Output:	12 V AC, 500 VA 60 Hz
Temperature:	40 - 100 degrees F

Appendix B
AE Sensor and Geophone Calibration Curves

PHYSICAL ACOUSTICS CORPORATION

CALIBRATION CERTIFICATE

''Sound Technology for Productivity and Safety''

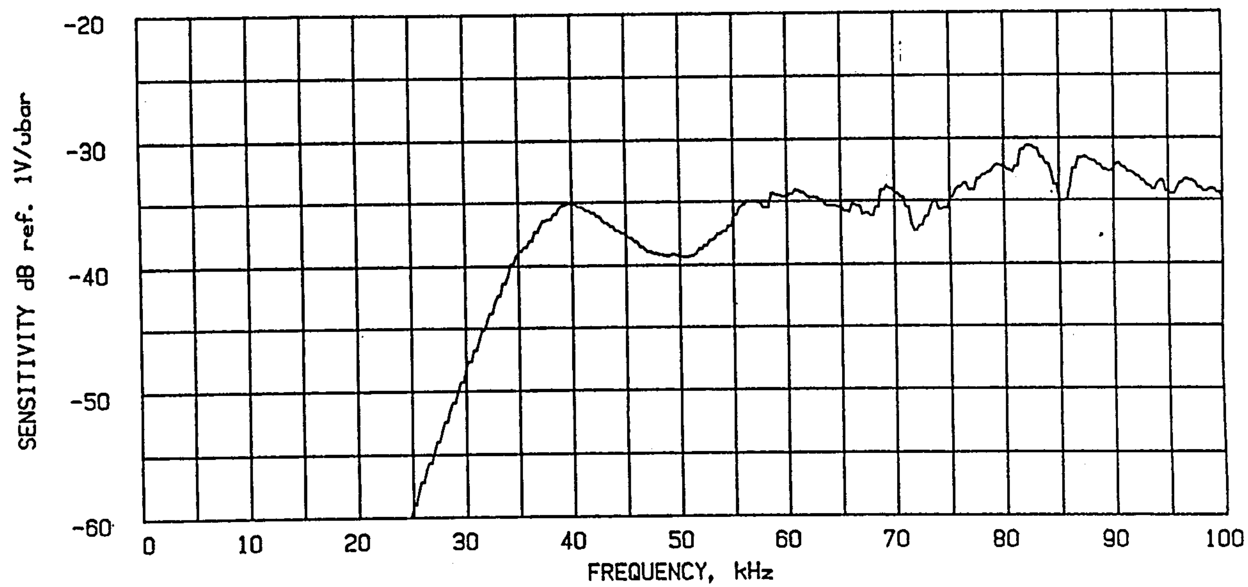
DUNEGAN CORPORATION

MODEL NUMBER: R6I

DATE: 02/08/91

SERIAL NUMBER: 754

TESTED BY:



PAC certifies that this sensor meets all performance, environmental, and physical standards established in applicable PAC specifications. Calibration methodology based on ASTM standard E976- ''Standard Guide for Determining the Reproducibility of Acoustic Emission Sensor Response''.

CC-6

B-1

ACOUSTICS CORPORATION

CALIBRATION CERTIFICATE

''Sound Technology for Productivity and Safety''

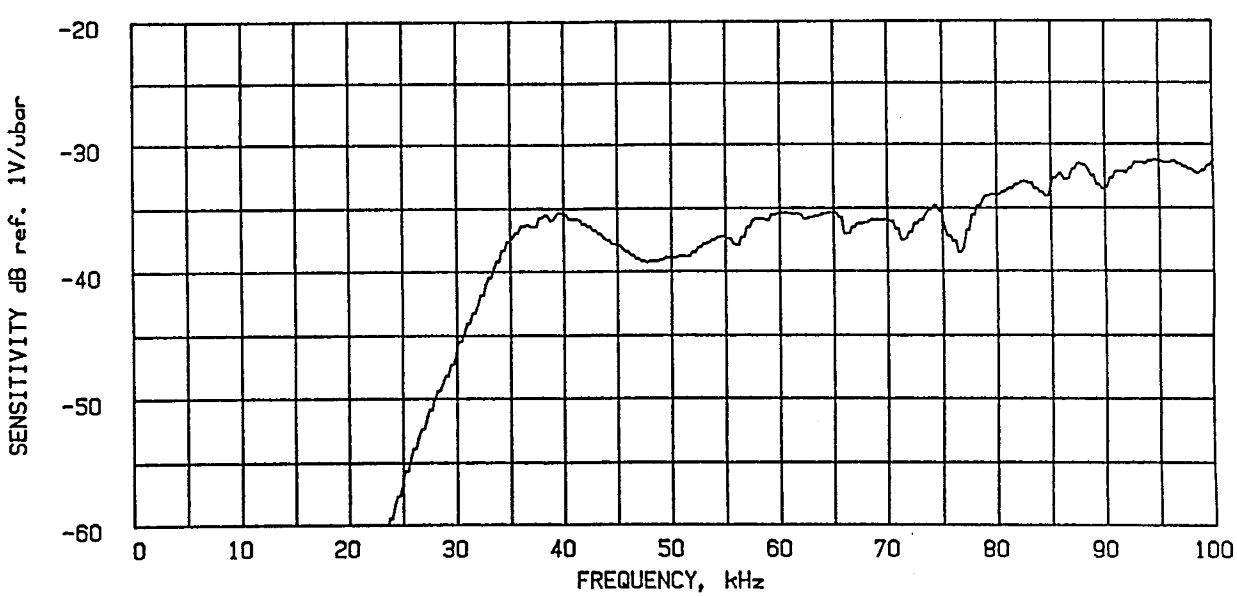
DUN CORPORATION

MODEL NUMBER: R6I

DATE: 02/08/91

SERIAL NUMBER: 755

TESTED BY:



PAC certifies that this sensor meets all performance, environmental, and physical standards established in applicable PAC specifications. Calibration methodology based on ASTM standard E976- ''Standard Guide for Determining the Reproducibility of Acoustic Emission Sensor Response''.

CC-6

B-2

PHYSICAL ACOUSTICS CORPORATION

CALIBRATION CERTIFICATE

''Sound Technology for Productivity and Safety''

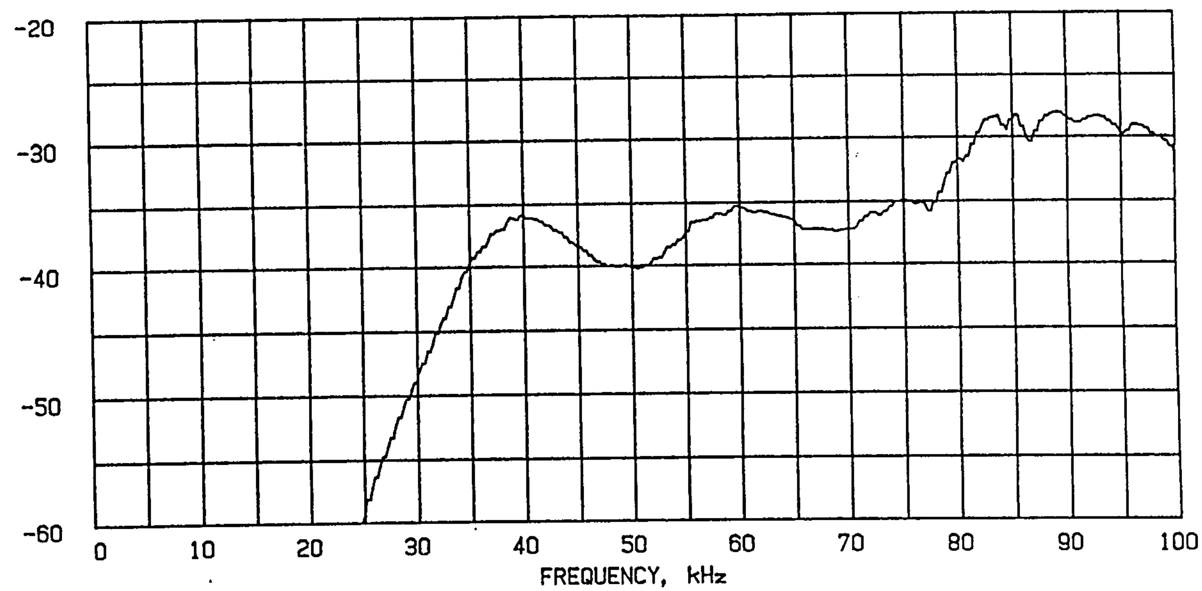
DUNE CORPORATION

MODEL NUMBER: R6I

DATE: 02/08/91

SERIAL NUMBER: 756

TESTED BY:



PAC certifies that this sensor meets all performance, environmental, and physical standards established in applicable PAC specifications. Calibration methodology based on ASTM standard E976- ''Standard Guide for Determining the Reproducibility of Acoustic Emission Sensor Response''.

CC-6

B-3

PHYSICAL
ACOUSTICS
CORPORATION

CALIBRATION CERTIFICATE

''Sound Technology for Productivity and Safety''

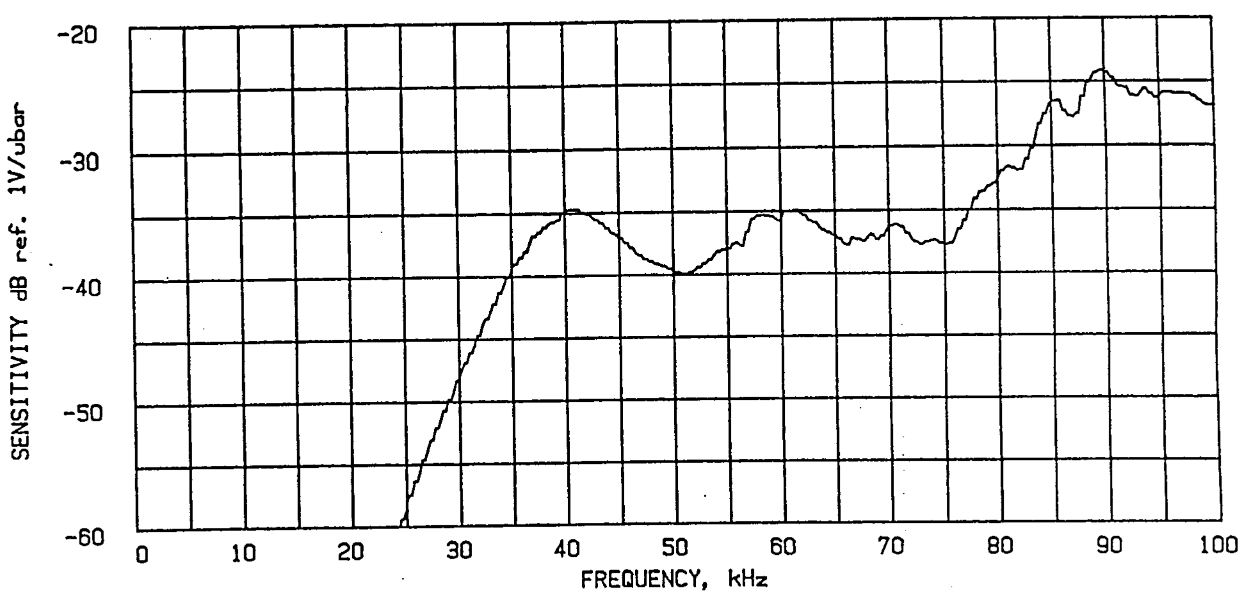
DUNE
CORPORATION

MODEL NUMBER: R6I

DATE: 02/08/91

SERIAL NUMBER: 759

TESTED BY:



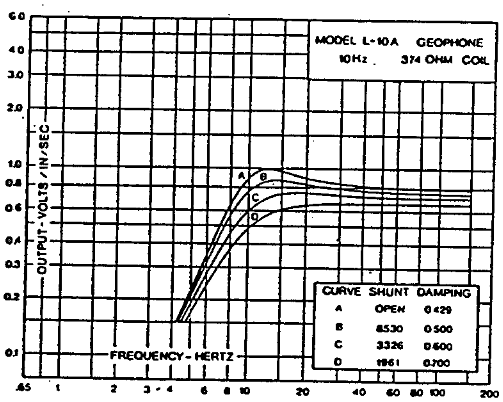
PAC certifies that this sensor meets all performance, environmental, and physical standards established in applicable PAC specifications. Calibration methodology based on ASTM standard E976- ''Standard Guide for Determining the Reproducibility of Acoustic Emission Sensor Response''.

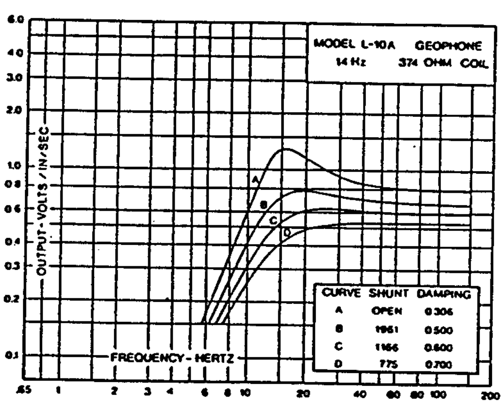
CC-6

B-4

TYPICAL CALIBRATION CURVES

GEOPHONE MODEL L-10A





B-5

Appendix C
Geophone Output Calculations

EVALUATION OF THRESHOLD LEVELS FOR SEISMIC SIGNALS IN RESPONSE TO BARGE COLLISION WITH COFFERDAM

INTRODUCTION

A barge colliding head-on with the cofferdam can be compared to a hollow piston striking the sheetpile cell structure. The piston moving with the velocity a_B represents an energy pulse which is partially transmitted into the structure, and partially reflected back when a collision occurs. The collision will probably produce damage to both the sheetpile cell and the barge. Nonlinearity of that process will probably result in an initial short burst of particle velocity followed by a more stable particle velocity pulse of lesser amplitude. This analysis is directed to evaluating the amplitude of the stable part of the pulse.

Input Conditions

The input conditions are characterized by the following data:

1. Barge

Length L = 120 ft.

Width W = 30 ft.

Height H = 20 ft.

Weight M = 270 tonn

Speed Y = 10 mi/hr.

Material: mild steel

Unit weight of steel 0_B = 7.9 g/ccm

Stress wave velocity in steel a_B = 19,000 ft/s

Seismic impedance $I_B = o_B \cdot a_B$

2. **Cofferdam**

Unit weight of fill (wet loose sand) $\rho_D = 1.45$ g/ccm

P-wave velocity in wet sand fill $a_{PD} = 1{,}600$ ft/s

Rayleigh wave velocity in wet sand $a_{RD} = 600$ ft/s

Seismic impedance: for P-waves $I_{DP} = \rho_D \cdot a_{PD}$

for R-waves $I_{DR} = \rho_D \cdot a_{RD}$

3. **Seismic Detectors**

Spacing between geophones A = 120 ft.

Sensitivity S = 0.8 V/in/sec

DISCUSSION

The time of collision/energy transfer from a barge to the cofferdam, and the length of the barge are related by the formula:

$$t = L / a_B = 6.3 \text{ milliseconds}$$

Velocity of P-wave produced by the collision in the fill multiplied by the duration of collision, t, determines the maximum range of a compressive disturbance forced by the collision in the fill:

$$D = t \cdot a_{PD} = 6.3 \times 10^{-3} \times 1600 = 10.1 \text{ ft.}$$

Based on time t, the dominant frequency generated by the collision should be approximately

$$f_D = 1/(2 \cdot t) = 79.36 \text{ Hz}$$

with a significant tendency to decrease with distance from the source because of dispersion.

Considering the width of the cell which is about six times larger than the size of a disturbance at the source, each collision is expected to generate head waves (P,S), and surface (Rayleigh) waves in the structure. Also, for geophones 120 ft. apart the longest distance for detecting barge collisions equals approximately R = 60 ft. Therefore a spherical spreading of stress waves in the fill between the source and a geophone can be expressed by the factor:

$$q = (D/R)^2 = 0.028 \text{ or } 1/36 \text{ approx.}$$

The spreading of Rayleigh waves will be limited to the surface of the structure. The water line on one side and the crown of the cofferdam on the other will probably channel those waves, reducing their attenuation to:

$$q_R = D/R = 0.168 \text{ or } 1/6 \text{ approx.}$$

For head-on collisions, the stress generated in a barge (hollow cylinder) distributed over the cross-section of the barge:

$$C_P = M/(L \cdot o_B)$$

will become redistributed over the front surface of the barge (hollow piston)

$$C_B = W \cdot H = 600 \text{ ft}^2$$

while being transferred into the structure

Considering the above analysis, minimum levels of particle velocity at a detection point within a distance R from a collision can be evaluated using the formula:

$$v_{RP} = v \cdot C_P/C_B \cdot 2I_B/(I_B + I_{DP}) \cdot (D/R)^2$$

for P-waves, and

$$v_{RR} = v \cdot C_P/C_B \cdot 21_B/(I_B + I_{DR}) \cdot D/R$$

for Rayleigh waves. S-waves are expected to generate signals of amplitude between those of P-waves and Rayleigh waves.

Concluding, the minimum particle velocity produced by an empty barge colliding head-on with the structure at mid-point between two geophone locations should reach:

$$v_{RP} = \underline{0.16 \text{ in/s}}$$

for P-waves, and

$$v_{RR} = \underline{0.98 \text{ in/s}}$$

for Rayleigh waves.

Consequently, the output from a geophone nearest to the collision should be on the order of:

$$G = v_{RP} \cdot S = \underline{130} \ \underline{\text{mV}} \text{ for P-waves,}$$

and

$$G_R = v_{RR} \cdot S = \underline{780} \ \underline{\text{mV}} \text{ for Rayleigh waves.}$$

The variance for these numbers can be as much as five-fold since the attenuation in the fill is unknown, and because of a generic approach to the geometry of the structure.

Note that for a barge full of a bulk cargo the seismic impedance of the barge (I_B) will decrease to its total weight because of lower global natural gravity, and lower stress wave velocity. At the same time the cross-section of the barge and cargo combined will be larger compared to an empty barge, therefore increasing the ratio C_P/C_B. Consequently, the output from

geophones should increase significantly. Also the duration of a collision will increase, resulting in a larger disturbance, and lower frequency of seismic response in the sheetpile cell.

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Prepared by,

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Appendix D
Procedures to Follow if Distress Warning System Reports Impact on the Cofferdam

PROCEDURES TO FOLLOW IF DISTRESS WARNING SYSTEM REPORTS AN IMPACT ON THE COFFERDAM.

A government contractor has installed a Distress Warning System on the upstream arm of the third stage cofferdam which continuously monitors the cofferdam for impact. If this system senses that an impact has occurred, one which exceeds a certain threshold level, the system will telephone the Mel Price control tower and give the following message:

Hello, this is telephone number 570-1721.
Alert condition 1 *(and/or 2)* exists.

Hello, this is telephone number 570-1721.
Alert condition 1 *(and/or 2)* exists.

The time is *(System announces time of day)*
The temperature is (System gives temperature)

The electricity is *(on/off). Power failure of 5-minutes or more generates the 'off' message.*

Sound level OK

Alert condition 1 (and/or 2) *exists.*

Battery condition OK.

Listen to the sound level for 15 seconds.

Indicate you have received warning message.

System pauses 5 seconds, acknowledge receipt by entering 5 5 5 from a touch tone phone.

System will recognize acknowledgement by phone number 899-1543. If not acknowledged, the system continues with this message:

Indicate you have received warning message by dialing 570-1721 within 60 seconds.

Dial 570-1721 within 60 seconds after the system hangs up. The system will recognize your acknowledgement after 10 rings.

Please make a visual inspection from the control room or from the upstream guidewall (if possible) and determine if some object has possibly struck the cofferdam. If you think something might have hit the cofferdam, call:

Jimmy Bissell at 314 899-0650 (work) or 314 921-0630 (home)

or

Larry Green at 314 899-0650 (work) or 618 498-6245 (home).

This system is considered somewhat experimental and may generate false alarms. If you feel that too many false alarms are generated, please call Patrick Conroy (ED-GF) at 331-8432.

Appendix E
Monthly Status Reports

APPENDIX E

MONTHLY STATUS REPORT

January 11, 1991

Mr. Earl Edris, P.E.
Research Civil Engineer
Soil Mechanics Division
Geotechnical Laboratory
U.S. Army Engineer Waterways Experiment Station
PO Box 631
Vicksburg, MS 39100-0631

MONTHLY STATUS REPORT - DEC. 1990
ACOUSTIC EMISSION COFFERDAM
DISTRESS WARNING SYSTEM AND
ANCILLARY ACOUSTIC EMISSION MONITORING
MELVIN PRICE LOCKS & DAM (PHASE III)
CONTRACT No. DACW39-91-C-0005

Dear Mr. Edris:

We are pleased to submit our monthly status report on the above project. The executed Contract was received from your office on December 2, 1990. On December 3, 1990 we ordered the Distress Warning Equipment from Physical Acoustics Corporation of Lawrenceville, New Jersey. Delivery of the equipment is expected during the second half of February 1991. During the latter part of December 1990, we discussed possible locations for our equipment trailer with the St. Louis District staff as well as the construction contractor. No decision was reached. A job site meeting in early January 1991 is expected to resolve this matter.

Sincerely,

GROUND ENGINEERING, INC.

J. A. deMonte

John A. deMonte, P.E.

JD:nd

cc: Patrick J. Conroy, P.E.
Eugene L. Fieldhammer, P.E.

February 6, 1991

Mr. Earl Edris, P.E.
Research Civil Engineer
Soil Mechanics Division
Geotechnical Laboratory
U.S. Army Engineer Waterways Experiment Station
PO Box 631
Vicksburg, MS 39100-0631

MONTHLY STATUS REPORT - JAN. 1991
ACOUSTIC EMISSION COFFERDAM
DISTRESS WARNING SYSTEM AND
ANCILLARY ACOUSTIC EMISSION MONITORING
MELVIN PRICE LOCKS & DAM (PHASE III)
CONTRACT No. DACW39-91-C-0005

Dear Mr. Edris:

We are pleased to submit our monthly status report on the above project. A job site meeting was held on January 22, 1991 to discuss the location of our Distress Warning System equipment trailer. The meeting was attended by representatives of the St. Louis District, the Resident Engineer's Office, the Lockmaster and Alberici-Eby. As a result of the meeting, it was agreed that the equipment trailer would be located on cell 98A. Delivery of the Distress Warning System is schedule for the last week of February or the first week of March 1991.

Sincerely,

GROUND ENGINEERING, INC.

J.A. deMonte

John A. deMonte, P.E.

JD:nd

cc: Patrick J. Conroy, P.E.
St. Louis District COE

March 11, 1991

Mr. Earl Edris, P.E.
Research Civil Engineer
Soil Mechanics Division
Geotechnical Laboratory
U.S. Army Engineer Waterways Experiment Station
PO Box 631
Vicksburg, MS 39100-0631

MONTHLY STATUS REPORT - FEBRUARY 1991
ACOUSTIC EMISSION COFFERDAM
DISTRESS WARNING SYSTEM AND
ANCILLARY ACOUSTIC EMISSION MONITORING
MELVIN PRICE LOCKS & DAM (PHASE III)
CONTRACT No. DACW39-91-C-0005

Dear Mr. Edris:

We are pleased to submit our monthly status report on the above project. The Distress Warning System (DWS) equipment trailer was delivered to the job site on February 18, 1991. Fabrication of the DWS unit by Physical Acoustics Corporation continued during the month. Delivery is expected within the next week to ten days.

We have planned the installation of the DWS sensor and cable system and expect to install it within the next two weeks.

Sincerely,

GROUND ENGINEERING, INC.

J. A. DeMonte

John A. deMonte, P.E.

JD:nd

cc: Patrick J. Conroy, P.E.
St. Louis District COE

April 5, 1991

Mr. Earl Edris, P.E.
Research Civil Engineer
Soil Mechanics Division
Geotechnical Laboratory
U. S. Army Engineer Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39100-0631

MONTHLY STATUS REPORT - MARCH 1991
ACOUSTIC EMISSION COFFERDAM
DISTRESS WARNING SYSTEM AND
ANCILLARY ACOUSTIC EMISSION MONITORING
MELVIN PRICE LOCKS & DAM (PHASE III)
CONTRACT No. DACW39-91-C-0005

Dear Mr. Edris:

We are pleased to submit our monthly status report on the above project. Fabrication of the DWS unit by Physical Acoustics Corporation (PAC) was completed during the month and it was shipped on March 28, 1991. Delivery is expected on or about April 4, 1991. The installation of the DWS sensor and cable system will commence upon arrival of the equipment. Research and theoretical analysis of sensor and geophone calibration methods and threshold values continued during the month. This work proceeded in our office, at PAC and by our consultant, Doctor Russell Miller.

Sincerely,

GROUND ENGINEERING, INC.

J.A. DeMonte

John A. deMonte, P.E.

JD:nd
cc: Pat Conroy, P.E.

May 6, 1991

Mr. Earl Edris, P.E.
Research Civil Engineer
Soil Mechanics Division
Geotechnical Laboratory
U. S. Army Engineer Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39100-0631

MONTHLY STATUS REPORT - APRIL 1991
ACOUSTIC EMISSION COFFERDAM
DISTRESS WARNING SYSTEM AND
ANCILLARY ACOUSTIC EMISSION MONITORING
MELVIN PRICE LOCKS & DAM (PHASE III)
CONTRACT No. DACW39-91-C-0005

Dear Mr. Edris:

We are pleased to submit our regular monthly status report on the above project.

The Distress Warning System (DWS) was delivered on April 5, 1991. Installation of sensor enclosure boxes and connecting cables was started on April 10 and completed on April 12, 1991. The installation was made by Dron Electric, Inc. Electric power supply to the Equipment Trailer was completed by Egizzi Electric, Inc. on April 11, 1991.

A representative of Physical Acoustics Corporation was on site from April 15 through April 17, 1991. During this period the DWS and all AE sensors, geophones and preamplifiers were installed. After installation the system was calibrated, tested, started up and placed on line at 4:42 P.M. on April 17, 1991. Said start-up marked the commencement of Contract Task A.2.a., System Operation. The enclosed photographs provide an overview of the system as installed.

Page 2
Mr. Earl Edris, P.E.
May 6, 1991

Any and all warning message telephone calls generated during an initial period of two to four weeks will be directed to a Ground Engineering, Inc. telephone in order to test for "false alarms". At the conclusion of this period, warning message calls will be directed to the Lock Control Room phone, 899-1543. The system will continue to dial this number until answered and acknowledged.

Preparation of a Report describing the work accomplished under Contract Task A.1., DWS Equipment and Installation has commenced, and completion is anticipated prior to May 15, 1991.

Sincerely,

GROUND ENGINEERING, INC.

J.A. DeMonte

John A. deMonte, P.E.

JD:nd

cc: Patrick J. Conroy, P.E.

June 10, 1991

Mr. Earl Edris, P.E.
Research Civil Engineer
Soil Mechanics Division
Geotechnical Laboratory
U. S. Army Engineer Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39100-0631

MONTHLY STATUS REPORT - MAY 1991
ACOUSTIC EMISSION COFFERDAM
DISTRESS WARNING SYSTEM AND
ANCILLARY ACOUSTIC EMISSION MONITORING
MELVIN PRICE LOCKS & DAM (PHASE III)
CONTRACT No. DACW39-91-C-0005

Dear Mr. Edris:

We are pleased to submit our regular monthly status report on the above project.

As indicated in our April Report, the Distress Warning System (DWS) was placed in operation on April 17, 1991. It was programmed to call Ground Engineering, Inc. (GEI) telephones with any Alarm (Alert) warning messages generated during a two to four-week test period. At the same time we were testing the call-in status report capabilities of the system. The DWS provides a report of the status of all elements monitored if called from an outside phone.

We experienced considerable difficulty in completing our telephone calls to the DWS. We often received a recorded message from the telephone company indicating that there was no answer at the DWS number. A representative of Physical Acoustics Corporation visited the site on May 8, 1991 and replaced the telephone message generator. However, this did not solve the problem. On May 14, 1991 we replaced the transceiver in the telephone dialer and this corrected the difficulty.

Page 2
Mr. Earl Edris, P.E.
June 10, 1991

On May 9, 1991 we received an Alarm (Alert) warning message at 7:18 a.m. The message "Alert Condition 2 Exists" indicated that one of the four Geophone channels had been activated. According to Larry Green of the Corps Area Office and Jim Rost of Alberici-Eby, the construction contractor, there were no site incidents that would have initiated an Alarm (Alert) warning message. We re-set the system on May 14, 1991 and received another 'false alarm' message initiated by a Geophone channel at approximately 10 p.m. that evening. We re-set the system on May 22, 1991 at 11:15 a.m. We also reduced the internal gain on the Geophone channels from 10 db to 4 db. Another 'false alarm' message was received at 2:06 p.m. on the same day. This message was also generated by a Geophone channel. We re-set the system on June 1, 1991 at approximately 12:00 noon and it has not initiated any 'false alarms' to date. We intend to continue to monitor system operation for another two to four-week period before re-programming it to direct any Alarm (Alert) warning messages to the Lock Control Room.

On May 6, 1991 we informally transmitted a draft instruction sheet for Lock Control Room personnel to the St. Louis District for review. The instruction sheet describes the DWS and provides an example of the Alarm warning message. It also advises the person who receives the Alarm warning message how to acknowledge said message and what further actions to take. As of May 31, 1991, the draft instruction is still under review by the District.

Sincerely,

GROUND ENGINEERING, INC.

J.A. deMonte

John A. deMonte, P.E.

JD:nd

cc: Patrick J. Conroy, P.E.

July 16, 1991

Mr. Earl Edris, P.E.
Research Civil Engineer
Soil Mechanics Division
Geotechnical Laboratory
U. S. Army Engineer Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39100-0631

MONTHLY STATUS REPORT - JUNE 1991
ACOUSTIC EMISSION COFFERDAM
DISTRESS WARNING SYSTEM AND
ANCILLARY ACOUSTIC EMISSION MONITORING
MELVIN PRICE LOCKS & DAM (PHASE III)
CONTRACT No. DACW39-91-C-0005

Dear Mr. Edris:

We are pleased to submit our regular monthly status report on the above project.

As indicated in our May Report, we received a number of "false alarm" messages generated by one of the Geophone channels of the Distress Warning System (DWS) during the month. This continued during the period as listed below:

May 22, 1991 . . . "false alarm" Warning Message "Alert Condition 2 Exists" receive at 2:06 p.m.

June 01, 1991 . . System reset.

June 14, 1991 . . "false alarm" Warning Message "Alert Condition 2 Exists" received at 10:22 p.m.

June 16, 1991 . . Warning Message "Alert Condition 2 and 3 Exists" received at 9:26 p.m.

June 16, 1991 . . Message "Alert Condition OK" received at 2:27 p.m.

June 16, 1991 . . Warning Message "Alert Condition 2 Exists" received at 2:41 p.m.

June 26, 1991 . . System reset.

No further Warning Messages were received after June 26 and during the remainder of the month or for the first two weeks of July.

The Warning Message "Alert Condition 2 and 3 Exists" received on June 16, 1991 indicated that the cause of the "false alarm" generated on June 14 was still in effect (Alert Condition 2). The "Alert Condition 3" Warning Message indicated that there had been a power outage of longer duration than the capacity of the Uninterruptible Power Supply provided with the DWS (approximately 3 1/2 hours). This proved to be the case; the project electrical power network had been shut down for maintenance from approximately 6:00 a.m. to 2:30 p.m. The "Alert Condition OK" message received at 2:27 p.m. was generated when electrical power was restored and the "Alert Condition 2 Exists" Warning Message received 14 minutes later at 2:41 p.m. was a reinstatement of the "false alarm" generated on June 14, 1991.

On June 1, 1991 we installed a strip chart recorder on channel 7 in order to attempt to discover which channel was generating the "false alarm" messages. The Warning Messages generated on June 14 and 16 were not recorded leading to the conclusion that channel 7 was not at fault.

A representative of Physical Acoustics Corporation (PAC), manufacturer of the equipment, visited the site on June 26, 1991 and installed a specially fabricated device which would indicate by a light the channel generating a Warning Message. He also took the Channel 6 Board with him to be tested at the PAC manufacturing facility. As of the date of this letter, all tests have been satisfactory, i.e., no malfunction has been discovered.

We are continuing to monitor the DWS in an attempt to isolate and correct the source of the "false alarm" Warning Messages.

Sincerely,

GROUND ENGINEERING, INC.

John A. deMonte, P.E.

JD:nd

cc: Patrick J. Conroy, P.E.
St. Louis District COE

August 12, 1991

Mr. Earl Edris, P.E.
Research Civil Engineer
Soil Mechanics Division
Geotechnical Laboratory
U. S. Army Engineer Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39100-0631

MONTHLY STATUS REPORT - JULY 1991
ACOUSTIC EMISSION COFFERDAM
DISTRESS WARNING SYSTEM AND
ANCILLARY ACOUSTIC EMISSION MONITORING
MELVIN PRICE LOCKS & DAM (PHASE III)
CONTRACT No. DACW39-91-C-0005

Dear Mr. Edris:

We are pleased to submit our regular monthly status report on the above project.

As indicated in our June Report, the Channel 6 Board was returned to Physical Acoustics Corporation (PAC) for testing. Such testing continued through the month of July without any malfunction occurring. The remaining three (3) Geophone channels (5, 7 and 8) continued to be operational and no "false alarm" Warning Messages were received during the month.

Despite the fact that the Channel 6 Board tested satisfactorily, PAC decided to replace it. The replacement Board was received on July 26 and installed on July 30, 1991. After installation the replacement Board was field tested using a number of controlled blows from a modified Proctor hammer. The board did not record the acoustic emissions generated by the hammer blows. The Channel 5 Board was installed in the Channel 6 Slot and functioned properly leading to the conclusion that the malfunction was in the replacement Board. Accordingly, it was returned to PAC for re-work.

As of July 31, 1991 the DWS is functioning with four (4) AE and three (3) Geophone Channels as we await receipt of the re-worked Channel 6 Board. The DWS is still programmed to telephone Ground Engineering, Inc. in the event of a signal, that is, it has not been programmed to call the Lock Control Room.

Sincerely,

GROUND ENGINEERING, INC.

J.A. DeMonte

John A. deMonte, P.E.

JD:nd

cc: Patrick J. Conroy, P.E.

September 20, 1991

Mr. Earl Edris, P.E.
Research Civil Engineer
Soil Mechanics Division
Geotechnical Laboratory
U. S. Army Engineer Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39100-0631

MONTHLY STATUS REPORT - AUGUST 1991
ACOUSTIC EMISSION COFFERDAM
DISTRESS WARNING SYSTEM AND
ANCILLARY ACOUSTIC EMISSION MONITORING
MELVIN PRICE LOCKS & DAM (PHASE III)
CONTRACT No. DACW39-91-C-0005

Dear Mr. Edris:

As indicated in our July Report, the replacement Distress Warning System (DWS) Channel 6 Board received on July 26, 1991 and installed on July 30, 1991 failed to record a "hammer test". It was returned to Physical Acoustics Corporation (PAC) on August 7, 1991 for further testing and repair. The Board was returned to us on August 27, 1991.

The four (4) AE channels (1, 2, 3 and 4) and three (3) Geophone channels (5,7 and 8) continued to be operational throughout the month of August without the generation of any "false alarm" messages. As of August 31, 1991, the DWS is functioning with four (4) AE and three (3) Geophone channels. The re-worked Channel 6 Board will be installed this month.

In the meantime, the DWS is still programmed to telephone Ground Engineering, Inc. in the event of a signal exceeding threshold settings. It has not been programmed to call the Lock Control Room.

We appreciate the opportunity to continue to provide professional services on this project.

Sincerely,

GROUND ENGINEERING, INC.

J. A. de Monte

John A. deMonte, P.E.

JD:nd

cc: Patrick J. Conroy, P.E. (COE)
Eugene Fieldhammer, P.E. (GEI)

October 9, 1991

Mr. Earl Edris, P.E.
Research Civil Engineer
Soil Mechanics Division
Geotechnical Laboratory
U. S. Army Engineer Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39100-0631

MONTHLY STATUS REPORT - SEPTEMBER 1991
ACOUSTIC EMISSION COFFERDAM
DISTRESS WARNING SYSTEM AND
ANCILLARY ACOUSTIC EMISSION MONITORING
MELVIN PRICE LOCKS & DAM (PHASE III)
CONTRACT No. DACW39-91-C-0005

Dear Mr. Edris:

As indicated in our August report, the replacement Distress Warning System (DWS) Channel 6 Board received on July 26, 1991 and installed on July 30, 1991 failed to record a "hammer test". It was returned to Physical Acoustics Corporation (PAC) on August 7, 1991 for further testing and repair. The Board was returned to us on August 27, and was installed on September 10, 1991.

As we entered the Equipment Trailer on that date, the DWS commenced an announcement that Alert Condition 2 (Geophone channel triggered) and Alert Condition 3 (power outage) Exist. This was obviously a "false alarm" message. We reset the DWS and installed the second re-worked Channel six board. We then proceeded to test each channel by striking it with a Modified

Proctor drop hammer which has become our standard testing procedure. Channels 2 through 7 responded normally, that is, the counts per second recorded were within the expected range. Channel 1 did not record on two separate tests. Channel 8 exceeded the warning message threshold on two separate tests and generated a warning message. We reset the system and left the job site at approximately 11:30 a.m. At 12:06 p.m. a "false alarm" warning message was received at a GEI telephone. We communicated the foregoing to PAC and they are considering what action to take. We have advised them that we believe it imperative that they send a technician to St. Louis and have him spend sufficient time at the site to correct the continual problems which we have encountered.

On September 20, 1991 we received a telephone call from Larry Green of the Area Engineers' office. He advised that our instrument cables had been damaged by the Contractor rock fill operation adjacent to connecting arc 92/102. Upon inspection we determined that all three cables at that location had been pulled from their fastenings to the sheet pile and one had been severed. We are in the process of having the cable spliced.

Four AE channels (1, 2, 3 & 4) and three Geophone channels (5, 7 & 8) were operational from September 1 through 10, 1991 without the generation of any "false alarm" message on September 10, 1991 in anticipation of a visit by a PAC service technician.

As a result, only AE channels 2, 3 & 4 were operational from September 10 through 30, 1991. The system is still programmed to telephone GEI with any warning messages generated.

We appreciate the opportunity to continue to provide professional services on this project.

Sincerely,

GROUND ENGINEERING, INC.

J. A. DeMonte

John A. deMonte, P.E.

cc: Patrick J. Conroy, P.E.
Eugene L. Fieldhammer, P.E.

November 13, 1991

Mr. Earl Edris, P.E.
Research Civil Engineer
Soil Mechanics Division
Geotechnical Laboratory
U. S. Army Engineer Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39100-0631

MONTHLY STATUS REPORT - OCTOBER 1991
ACOUSTIC EMISSION COFFERDAM
DISTRESS WARNING SYSTEM AND
ANCILLARY ACOUSTIC EMISSION MONITORING
MELVIN PRICE LOCKS & DAM (PHASE III)
CONTRACT No. DACW39-91-C-0005

Dear Mr. Edris:

As indicated in our September Report, we visited the site on September 10, 1991 to install the Distress Warning System (DWS) Channel 6 Board which had been reworked by Physical Acoustics Corporation (PAC) during August. The DWS malfunctioned in an erratic manner during this site visit. The Channel 1 Board did not record and the Channel 8 Board initiated a Distress Warning Message upon performance of our standard "hammer test". This information was relayed to PAC and they debated for some time whether to have the Boards returned or to send a technician to attempt field repair.

Page 2
Mr. Earl Edris, P.E.
November 13, 1991

Finally, on October 15, 1991 one of their Engineering staff visited the site and took the Channel 1 and 8 Boards with him to their home office. The reworked Boards had not been received by Ground Engineering, Inc. as of October 31, 1991.

We appreciate the opportunity to provide professional services on this project.

Sincerely,

GROUND ENGINEERING, INC.

J.A. DeMonte

John A. deMonte, P.E.

JD:nd

cc: Patrick Conroy, P.E.

Eugene L. Fieldhammer, P.E.

January 20, 1992

Mr. Earl Edris, P.E.
Research Civil Engineer
Soil Mechanics Division
Geotechnical Laboratory
U. S. Army Engineer Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39100-0631

MONTHLY STATUS REPORT - NOVEMBER 1991
ACOUSTIC EMISSION COFFERDAM
DISTRESS WARNING SYSTEM AND
ANCILLARY ACOUSTIC EMISSION MONITORING
MELVIN PRICE LOCKS & DAM (PHASE III)
CONTRACT No. DACW39-91-C-0005

Dear Mr. Edris:

As indicated in our October Report, the Distress Warning System (DWS) Channel 1 and 8 Boards, which were not functioning properly, were picked up for rework by a member of the Physical Acoustics Corporation (PAC) engineering staff on October 15, 1991. The reworked Boards were returned to us early in November.

During the week of November 11, 1991, we installed the reworked Boards and attempted to field splice the Channel 3,4, 7 and 8 cables which had been severed by Alberici-Eby construction operations on September 20, 1991. We tested the DWS extensively after installation of the reworked Boards and field splicing the cables. As usual, our test consisted of using specific energy by

dropping a standard Proctor hammer on a sheet pile adjacent to the sensor box and recording the AE or Geophone signals at the DWS.

The reworked Channel 1 Board did not record even though tested in the Channel 2 slot which was functional. It was returned to PAC on or about November 15, 1991 for further corrective work.

Channels 3, 4 and 8 did not record during the Drop Hammer test indicating that the field splices made in the cables were unsatisfactory. Channel 7 did record indicating that the splice was satisfactory.

As a result of the foregoing, the DWS Channels which were found to be operational were 2, 5, 6 and 7.

We discussed this situation with PAC and suggested that they send a technician to St. Louis to thoroughly check the DWS unit. PAC in turn thought it might be best for us to return the DWS to their shop for such a check. This difference of opinion had not been resolved as of November 30, 1991.

We appreciate the opportunity to provide professional services on this project.

Sincerely,

GROUND ENGINEERING, INC.

J.A. DeMonte

John A. deMonte, P.E.

JD:nd

cc: Patrick J. Conroy, P.E. & Eugene L. Fieldhammer, P.E.

January 20, 1992

Mr. Earl Edris, P.E.
Research Civil Engineer
Soil Mechanics Division
Geotechnical Laboratory
U. S. Army Engineer Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39100-0631

MONTHLY STATUS REPORT - DECEMBER 1991
ACOUSTIC EMISSION COFFERDAM
DISTRESS WARNING SYSTEM AND
ANCILLARY ACOUSTIC EMISSION MONITORING
MELVIN PRICE LOCKS & DAM (PHASE III)
CONTRACT No. DACW39-91-C-0005

Dear Mr. Edris:

As indicated in our November report, we and Physical Acoustics Corporation (PAC) were discussing the relative merits of PAC sending a technician to St. Louis to check the Distress Warning System (DWS) or returning the unit to PAC for a shop test and check. It was finally decided that PAC would send a technician.

The technician spent the day at the site on December 20, 1991. During that time he thoroughly checked the operation of the DWS, installed the reworked Channel 1 Board which he brought with him, and spliced the Channel 3, 4, 7 and 8 cables. At the completion of his work, the system was tested with our usual "Drop Hammer Test" with the following results:

1. The DWS chassis was in good condition and operating satisfactorily.
2. The reworked Channel 1 Board was not operational, whether installed in the Channel 1 or 2 slot. The Channel 2 slot was known to function properly. The Channel 1 Board was taken back to PAC by the technician upon his departure.
3. Channels 3 and 7 did not record leading to the conclusion that there were internal breaks in the cable which were not apparent in a visual inspection. The only solution suggested was the replacement of the cable from the Instrument Trailer to the Channel 3/7 sensor box.

The necessity of installing a replacement cable was discussed with Pat Conroy of the St. Louis District on December 23, 1991. He in turn discussed it with Earl Edris of WES. It was decided to continue the remainder of the work under this contract without Channels 3 and 7 in operation. The rationale for this decision was that the Channel 3/7 sensor box is located at the juncture of the north leg of the cofferdam and the upstream guide wall. This location is such that a barge impact would be very unlikely, if not impossible. On December 20, 1991 we placed the operable Channel 3 Board in the Channel 1 slot before leaving the

site, thus rendering Channel 1 operational. As a result, Channels 1, 2, 4, 5, 6 and 8 are now operational.

During the December 23, 1991 discussion, we informed Pat Conroy that we were ready to transfer the receipt of any Distress Warning Signals to the Lock Control Room. It was arranged that we would meet with the lockmaster at the site on December 31, 1991 in order to do so. It developed that it was not possible to arrange for the attendance of all necessary Corps of Engineers personnel at this proposed meeting, and it was postponed until sometime in early January 1992. A meeting date was set for January 23, 1992 and then rescheduled for Tuesday, February 4, 1992, because of a more pressing commitment at Lock and Dam No. 25.

We continue to appreciate the opportunity to provide professional services on this project.

Sincerely,

GROUND ENGINEERING, INC.

J.A. DeMonte

John A. deMonte, P.E.

JD:nd

cc: Pat Conroy, P.E.
Eugene L. Fieldhammer, P.E.

February 21, 1992

Mr. Earl Edris, P.E.
Research Civil Engineer
Soil Mechanics Division
Geotechnical Laboratory
U. S. Army Engineer Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39100-0631

MONTHLY STATUS REPORT - JANUARY 1992
ACOUSTIC EMISSION COFFERDAM
DISTRESS WARNING SYSTEM AND
ANCILLARY ACOUSTIC EMISSION MONITORING
MELVIN PRICE LOCKS & DAM (PHASE III)
CONTRACT No. DACW39-91-C-0005

Dear Mr. Edris:

As indicated in our December 1991 Report, we had planned to meet with appropriate Corps of Engineers personnel at the site on December 31, 1991. At that meeting we were to arrange to trans fer receipt of Distress Warning Messages to the Lock Control Room. It was not possible for all necessary Corps personnel to attend on that date. Consequently, the meeting was postponed to January 23, 1992 and subsequently to February 4, 1992.

We appreciate the opportunity to provide professional services on this project.

Sincerely,

GROUND ENGINEERING, INC.

John A. deMonte, P.E.

JD:nd

cc: Patrick J. Conroy, P.E.
Eugene L. Fieldhammer, P.E.

March 10, 1992

Mr. Earl Edris, P.E.
Research Civil Engineer
Soil Mechanics Division
Geotechnical Laboratory
U. S. Army Engineer Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39100-0631

MONTHLY STATUS REPORT - FEBRUARY 1992
ACOUSTIC EMISSION COFFERDAM
DISTRESS WARNING SYSTEM AND
ANCILLARY ACOUSTIC EMISSION MONITORING
MELVIN PRICE LOCKS & DAM (PHASE III)
CONTRACT No. DACW39-91-C-0005

Dear Mr. Edris:

As indicated in our January 1992 report, we had planned to meet with appropriate Corps of Engineers personnel at the site during that month. At the meeting we were to arrange to transfer receipt of Distress Warning System (DWS) messages to the Lock Control Room. It was not possible for all necessary Corps personnel to attend on the date selected. Consequently, the meeting was postponed to February 4, 1992.

On that date we met with Pat Conroy of the St. Louis District, the acting Lockmaster and three lock control room personnel. We generally described the DWS and its operation and Pat Conroy gave the acting Lockmaster the attached instruction sheet entitled, "Procedures To Follow If Distress Warning System Reports An Impact On The Cofferdam". In addition, we provided them with a key to the instrument trailer and showed them how to turn the DWS off, should it generate repetitive false alarm warning messages. We also posted the attached sign in the instrument trailer and identified the On/Off switch by taping the attached message above it in the DWS cabinet. We then proceeded to re-program the DWS to direct all warning message telephone calls to the lock control room at 899-1543.

After the above meeting ended we conducted our standard "drop hammer" test to determine if all six active channels were recording. Channels 3 and 7 were disabled due to their accidental severance by construction operations in September 1991. Several test attempts have been made to locate the severed cable positions. In this test two geophone channel boards failed to record and the channel 8 slot did not record with a known operating board installed. The two dysfunctional geophone channel boards were returned to PAC for rework. We understand they will sent to us shortly.

Sincerely,

GROUND ENGINEERING, INC.

J.A. deMonte

John A. deMonte, P.E.

cc: Patrick J. Conroy, P.E.
Eugene L. Fieldhammer, P.E.

April 8, 1992

Mr. Earl Edris, P.E.
Research Civil Engineer
Soil Mechanics Division
Geotechnical Laboratory
U. S. Army Engineer Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39100-0631

MONTHLY STATUS REPORT - MARCH 1992
ACOUSTIC EMISSION COFFERDAM
DISTRESS WARNING SYSTEM AND
ANCILLARY ACOUSTIC EMISSION MONITORING
MELVIN PRICE LOCKS & DAM (PHASE III)
CONTRACT No. DACW39-91-C-0005

Dear Mr. Edris:

As indicated in our February 1992 report, two geophone channel boards failed to record when tested with our standard "Drop Hammer Test" (DH Test) on February 4, 1992. These boards were returned to Physical Acoustics Corporation (PAC) for rework but had not been returned as of February 29, 1992.

During the month of March, we visited the site three times. These visits occurred on March 1, 8 and 29, 1992.

For the March 1, 1992 visit we engaged the services of an audio technician to assist in trouble-shooting the continuity of the connecting cables which was still suspect due to their severance by construction activity on September 20, 1991.

Page 2
Mr. Earl Edris
April 8, 1992

During this visit we conducted a standard DH Test which produced the same result as that conducted on February 4, 1992. That is, channels 3, 7 and 8 were not recording. We proceeded to visually check the connecting cables for these three channels and discovered another break in the channel 3 cable at cell 102. The technician spliced it and we conducted another test with the same results. We then proceeded to open the channel 3/7 and 4/8 sensor boxes. When we did so, we discovered that the channel 3, 7 and 8 cables were physically disconnected. The cause of this situation is unclear. Either the PAC technician who spliced the cables on December 20, 1991 did not reconnect them or they were tampered with. Neither explanation appears reasonable and we probably will never know the actual cause of the disconnected cables. After reconnecting cables 3, 7 and 8 and splicing cable 3, as noted above, channel 7 recorded AE signals but channels 3 and 8 did not.

We returned to the site, accompanied by the audio technician on March 8, 1992. A DH Test produced the same result as that conducted on March 1, 1992, that is, channels 3 and 8 did not record. The technician discovered a short circuit in the cable 3 splice which he had made the previous week and re-spliced it. He also discovered a break in the channel 8 cable at connecting arc 102/103 and repaired it. A second series of DH Tests indicated that all channels were operational. All four geophone

channels were tested by installing each of the two available geophone boards in two channel slots sequentially. This procedure was necessary since we were still awaiting return of the two geophone boards sent to PAC for rework in February.

The boards were received on March 26 and installed on March 29, 1992. A DH Test on that date indicated that channel 1, 2, 5, 6 and 8 were operational. Channels 3, 4 and 7 did not record. We increased the channel 1 through 4 gain from 0 to 6 db on the second amplifier (jumper JS7) and the channel 7 gain to 10 db on the third amplifier (jumper JS5). A further DH Test indicated that channels 3 and 7 were recording. Channel 4 did not record. We installed the channel 1 board in slot 4 and the channel 4 board in slot 1 and performed another DH Test. Channel 1 recorded the AE signals generated but channel 4 did not. This led to the conclusion that all channel boards are operational but there is still a discontinuity in the channel 4 cable. It is possible that one of the splices in the cable has failed. We shall attempt to discover and rectify this condition in the next few days. Finally we reduced the channel 7 gain to 6 db which appears to be satisfactory. This was accomplished by setting jumper JS5 to 0 and JS7 to 6 db.

Page 4
Mr. Earl Edris
April 8, 1992

We wish to express our continued appreciation in providing professional services on this project.

Sincerely,

GROUND ENGINEERING, INC.

J.A. deMonte

John A. deMonte, P.E.

JD:nd

cc: Patrick J. Conroy, P.E.
Eugene L. Fieldhammer, P.E.

May 4, 1992

Mr. Earl Edris, P.E.
Research Civil Engineer
Soil Mechanics Division
Geotechnical Laboratory
U. S. Army Engineer Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39100-0631

MONTHLY STATUS REPORT - APRIL 1992
ACOUSTIC EMISSION COFFERDAM
DISTRESS WARNING SYSTEM AND
ANCILLARY ACOUSTIC EMISSION MONITORING
MELVIN PRICE LOCKS & DAM (PHASE III)
CONTRACT No. DACW39-91-C-0005

Dear Mr. Edris:

Referring to our March 1992 Report, all eight (8) channel boards continued to be operational, but only channels, 1, 2, 3, 5, 6, 7 and 8 recorded AE signals during our standard "Drop Hammer Test" (DHT).

On April 5, 1992 we returned to the site accompanied by our audio technician to continue to trouble-shoot the continuity of connecting cable 4 which was suspected to be the cause of the failure of channel 4 to record. We spent approximately three hours testing for continuity and visually inspecting the 900 foot long cable. The results of the continuity tests indicated that the cable was "open", that is non conductive. However, our detailed inspection failed to uncover any visually apparent

Page 2
Mr. Earl Edris
May 4, 1992

damage to the cable insulation which would indicate a possible break in the conductors. Consequently, we were unable to undertake any repair efforts.

We have expended approximately 60 hours visually inspecting, trouble-shooting and splicing the four cables which were severed by construction activities on September 20, 1991. Despite this effort, it now appears that we can anticipate having only seven operational channels for the remainder of the project. These are 1, 2, 3, 5, 6, 7 and 8, as given above.

We appreciate the opportunity to provide professional services on this project.

Sincerely,

GROUND ENGINEERING, INC.

J.A. deMonte

John A. deMonte, P.E.

JD:nd

cc: Patrick J. Conroy, P.E.
Eugene L. Fieldhammer, P.E.

June 9, 1992

Mr. Earl Edris, P.E.
Research Civil Engineer
Soil Mechanics Division
Geotechnical Laboratory
U. S. Army Engineer Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39100-0631

MONTHLY STATUS REPORT - MAY 1992
ACOUSTIC EMISSION COFFERDAM
DISTRESS WARNING SYSTEM AND
ANCILLARY ACOUSTIC EMISSION MONITORING
MELVIN PRICE LOCKS & DAM (PHASE III)
CONTRACT No. DACW39-91-C-0005

Dear Mr. Edris:

As indicated in our April 1991 Report, all eight channel boards were operational, but only channels 1, 2, 3, 5, 6, 7 and 8 recorded AE signals during our standard "Drop Hammer Test" (DH test). Channel 4 did not record due to an apparent cable break.

On May 28, 1992 we conducted our monthly inspection and test of the Distress Warning System (DWS). This included a visual inspection of all equipment, sensor stations and connecting cables, activating the system self test circuit for each channel and conducting our standard Drop Hammer Test (DH test). The result of the foregoing monthly inspection and test was as follows: a) no visually discernible damage to the system was observed. b) all channels performed satisfactorily upon activation

of the self-test circuit. c) Only channels 1, 5 and 6 recorded signals generated by a DH test. Channels 2, 3, 4, 7 and 8 did not record. In order to verify the above results, we conducted two additional DH tests. During the first, we increased the gain on the second amplifier to 10 db and during the second we also increased the gain on the third amplifier to 10 db. In each case the previous standard setting had been 4 db. Neither DH test produced signals recorded on channels 2, 3, 7 and 8. In addition, none of the channel 2, 3, 7 or 8 front panel Alarm LEDs indicated activity during any of the three DH tests. We did not test channel 4 during the last two DH tests since our testing during April 1992 had concluded that it was permanently out of service. This was confirmed by our first DH test on May 28, 1992.

The May monthly inspection and test conclusions are that the severance of connecting cables due to the construction incident on September 20, 1991 led to an unknown number of cable discontinuities. We were able to visually identify and repair several of these, but apparently others are not visually discernible. We are again arranging for our audio technician to make a further attempt to locate and repair the cable breaks. In the meantime, the only active channels are 1, 5 and 6. Channel 1 is an AE channel, and 5 and 6 are geophone channels.

Please call us if you should have any questions regarding the above.

Sincerely,

GROUND ENGINEERING, INC.

J.A. deMonte

John A. deMonte, P.E.

JD:nd

copy to: Patrick J. Conroy, P.E.
Eugene L. Fieldhammer

August 12, 1992

Mr. Earl Edris, P.E., Research Civil Engineer
Soil Mechanics Division
Geotechnical Laboratory
U. S. Army Engineer Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39100-0631

MONTHLY STATUS REPORT - JUNE 1992
ACOUSTIC EMISSION COFFERDAM
DISTRESS WARNING SYSTEM AND
ANCILLARY ACOUSTIC EMISSION MONITORING
MELVIN PRICE LOCKS & DAM (PHASE III)
CONTRACT No. DACW39-91-C-0005

Dear Mr. Edris:

Due to the unavailability of our audio technician to continue our search for faults in the system connecting cables, we did not visit the project site during the month of June. We did make several telephone status checks on the operation of the equipment using the procedure built into the system. No change was indicated since our May Status Report. At that time, the only active channels were 1, 5 and 6. Channel 1 is an AE channel and 5 and 6 are geophone channels.

We appreciate the opportunity to provide professional services on this project.

Sincerely,

GROUND ENGINEERING, INC.

J.A. deMonte

John A. deMonte, P.E.

JD:nd

cc: Patrick J. Conroy, P.E.
Eugene L. Fieldhammer, P.E.

August 12, 1992

Mr. Earl Edris, P.E.
Research Civil Engineer
Soil Mechanics Division
Geotechnical Laboratory
U. S. Army Engineer Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39100-0631

MONTHLY STATUS REPORT - JULY 1992
ACOUSTIC EMISSION COFFERDAM
DISTRESS WARNING SYSTEM AND
ANCILLARY ACOUSTIC EMISSION MONITORING
MELVIN PRICE LOCKS & DAM (PHASE III)
CONTRACT No. DACW39-91-C-0005

Dear Mr. Edris:

We visited the site on July 19, 1992 accompanied by our audio technician. While there, we conducted our usual Drop Hammer Test (DH Test) on all channels. Channels 1, 5 and 6 recorded signals normally. Channels 2, 3, 4, 7 and 8 did not record. We once again visually inspected all cables for evidence of failure of any type without result.

We discussed the matter with Pat Conroy of the St. Louis District and suggested several alternate methods of proceeding as listed in our attached memorandum dated July 28, 1992. We also discussed our connecting cable problems with the manufacturer, Cooper Industries, Belden Division, as described in the attached memorandum, also dated July 28, 1992.

Page 2
Mr. Earl Edris
August 12, 1992

After the foregoing analysis and discussion, we conclude that there are only two alternatives open to us: (1) replace all connecting cables, or (2) defer action at this time in which case the only active channels will be 1 5 and 6. Channel 1 is an AE channel and 5 and 6 are geophone channels. However, if we do not replace the cables, it is possible that one or more of the three remaining active channels will cease to record as the existing cables continue to deteriorate with exposure to the weather. Since replacing all cables will incur additional cost, we await your decision on this issue.

We appreciate the opportunity to provide professional services on this project.

Sincerely,

GROUND ENGINEERING, INC.

J. A. deMonte

John A. deMonte, P.E.

JD:nd

cc: Patrick J. Conroy, P.E.
Eugene L. Fieldhammer, P.E.

September 2, 1992

Mr. Earl Edris, P.E.
Research Civil Engineer
Soil Mechanics Division
Geotechnical Laboratory
U. S. Army Engineer Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39100-0631

MONTHLY STATUS REPORT - AUGUST 1992
ACOUSTIC EMISSION COFFERDAM
DISTRESS WARNING SYSTEM AND
ANCILLARY ACOUSTIC EMISSION MONITORING
MELVIN PRICE LOCKS & DAM (PHASE III)
CONTRACT No. DACW39-91-C-0005

Dear Mr. Edris:

We made our regular monthly visit to the project site on August 17, 1992. Upon arrival, we conducted the standard Drop Hammer Test (DHT) to verify that channels 1, 5 and 6 were still recording. These were the only ones operational in July. The DH test did not produce a recordable signal on any of the eight channels in the system. We then made a visual inspection of the cables to determine if they had further damage. This revealed that all cables had been severed at about the midpoint of Cell 91. The severed ends of the cables appeared torn and crushed as if caused by some type of impact, presumably from construction equipment.

After this finding was reported to WES and the St. Louis District, possible remedial measures were discussed. These included: an attempt to splice the severed cables or completely replace all cables; the probability that all of the breaks in the cables could be successfully determined and spliced was not good, based on previous experience; and the DWS monitoring program was near termination. It was scheduled to end on December 31, 1992 in any event.

In view of the above, we were instructed to cease DWS monitoring, demobilize all equipment and prepare our Final Report as required by Contract Task E.

Accordingly, on August 30, 1992 we removed the DWS sensor stations, the connecting cables and all other equipment from the project site. In the removal, we attempted to salvage those portions of the connecting cables which appeared undamaged. As we detached the cables from the cofferdam guard rail, we discovered that they had been severed or crushed in at least twelve places. Although the first two hundred feet of each cable could be wound on reels, crimps were visible and other breaks were suspected. The remainder was damaged to the point that it was necessary to discard it. We believe the additional breaks and damaged cables must have occurred subsequent to our site visit on July 19, 1992, since we made a thorough visual inspection of the cables at that time.

We are currently preparing the final report and expect to submit it on or before September 30, 1992.

The opportunity to provide professional services on this project is appreciated.

Sincerely,

GROUND ENGINEERING, INC.

J.A. deMonte

John A. deMonte, P.E.

JD:nd

cc: Patrick J. Conroy, P.E.
Eugene L. Fieldhammer, P.E.

September 30, 1992

Mr. Earl Edris, P.E.
Research Civil Engineer, Soil Mechanics Division
Geotechnical Laboratory
U. S. Army Engineer Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39100-0631

MONTHLY STATUS REPORT - SEPTEMBER 1992
ACOUSTIC EMISSION COFFERDAM
DISTRESS WARNING SYSTEM AND
ANCILLARY ACOUSTIC EMISSION MONITORING
MELVIN PRICE LOCKS & DAM (PHASE III)
CONTRACT No. DACW39-91-C-0005

Dear Mr. Edris:

As reported in our August 1992 Status Report, all DWS monitoring ceased on August 17, 1992, and all DWS equipment was removed from the site on August 30, 1992. This completed all work on the above project except the preparation of the Final Report required by Task E of the Contract.

The Final Report was completed and submitted on September 30, 1992, thus completing the provision of all services required under the above contract.

We have appreciated the opportunity to provide professional services on this project, and wish to thank you and Pat Conroy for the professional consideration and assistance which you so generously provided during execution of the work.

Sincerely,

GROUND ENGINEERING, INC.

John A. deMonte, P.E.

JD:nd
cc: Patrick J. Conroy, P.E.
Eugene L. Fieldhammer, P.E.

Appendix F
Report of Findings of Research Effort; Acoustic Emission Monitoring During Cofferdam Unwatering; Melvin Price Locks and Dam (Phase III)

REPORT OF FINDINGS OF RESEARCH EFFORT

ACOUSTIC EMISSION MONITORING

DURING COFFERDAM UNWATERING

MELVIN PRICE LOCKS & DAM (PHASE III)

CONTRACT NO. DACW39-91-C-0005; TASK C

TO

U. S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION

VICKSBURG, MISSISSIPPI

BY

GROUND ENGINEERING, INC.
GEOTECHNICAL ENGINEERS

ST. LOUIS, MISSOURI

NOVEMBER 26, 1990 GEI PROJECT No. 60799

November 26, 1990

Mr. Earl Edris, P.E.
Research Civil Engineer
Soil Mechanics Division
Geotechnical Laboratory
U.S. Army Engineer Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39100-0631

REPORT OF FINDINGS OF RESEARCH EFFORT
ACOUSTIC EMISSION MONITORING DURING COFFERDAM UNWATERING
MELVIN PRICE LOCKS AND DAM (PHASE III)
CONTRACT NO. DACW39-91-C-0005; TASK C

Dear Mr. Edris:

We are pleased to present this Report of findings resulting from acoustic emission (microseismic) monitoring during unwatering of the Phase III cofferdam of the Melvin Price Locks & Dam on the Mississippi River near Alton, Illinois.

The opportunity to conduct this study is appreciated, and we wish to express our appreciation and thanks for the cooperation and assistance of the St. Louis District, Corps of Engineers and the general contractor, J. S. Alberici Construction Company-Eby.

Sincerely,

GROUND ENGINEERING, INC.

John A. deMonte, P.E.

Eugene L. Fieldhammer, P.E.

JD:EF:nd

cc: Patrick J. Conroy, P.E.
St. Louis District, Corps of Engineers

1.0 BACKGROUND

Ground Engineering, Inc. recently completed Contracts Number DACW39-86-C-0048, DACW39-89-M-2078 and DACW39-90-M-0858 entitled, respectively, "Acoustic Emission Monitoring of Cofferdam Performance; Locks & Dam 26 (Replacement) Phase II", "Acoustic Emission Monitoring of Cofferdam Performance During Rewatering; Melvin Price Locks & Dam (formerly Locks & Dam 26) Phase II", and "Acoustic Emission Monitoring During Extraction Of Sheetpiles From Cell 72; Melvin Price Locks & Dam (Phase III)".
These research efforts were performed for the U. S. Army Corps of Engineers, Waterways Experiment Station and administered by the Geotechnical Laboratory, Soil Mechanics Division. Reports describing the work accomplished were submitted in September 1988, July 1989 and May 1990. Each of these Reports is hereafter referred to by month and year of submittal.

The September 1988 Report concluded that there was a correlation between acoustic emissions (AE) generated within the unwatered cofferdam and the differential head caused by the fluctuating level of the Mississippi River. This correlation was graphically demonstrated by extremely high microseismic readings as the river rose to flood level in October/November 1986.

One of several objectives of the July 1989 Report was to confirm the above correlation. Limited data was obtained during rewatering, because the elevation of the Mississippi River and consequent differential head on the cofferdam remained at a low level.

The May 1990 Report concluded that microseismic emissions due to friction developed in the sheetpile interlocks during extraction were in a range consistent with those caused by the substantial hydrostatic loading on the cofferdam cells during the river flood period of October/November 1986. It also concluded that the correlation of count and event rates generated by flood stage hydrostatic loading and extraction forces suggested that sheetpile interlock shear provides a significant contribution to cofferdam stability.

2.0 OBJECTIVES

The objectives of the field measurements and research effort described below were: 1) to obtain continuous records of acoustic emissions generated in a large cellular earth-filled structure, such as the Melvin Price Locks and Dam Phase III Cofferdam, during periods of known load variation: 2) to correlate and compare these AE records with those presented in the earlier Reports; 3) to correlate and compare these AE records with those obtained during the October/November 1986 high water period; and 4) to develop additional understanding of acoustic emission generation and transmission.

3.0 SITE CONFIGURATION

Melvin Price Locks and Dam has been under construction since 1979. It is located at mile 200.78 on the Mississippi River approximately two miles downstream from the previous Locks & Dam 26 near Alton, Illinois, recently demolished. Phase I included

the construction of five gate bays on the Missouri side of the river. Phase II included two additional gate bays and the main lock. Phase III will add the second lock and complete the project. Construction of Phases I and II was accomplished in the 'dry' within cellular sheet pile cofferdams. Phase III construction will utilize the same procedure. Selected cells of the Phase II cofferdam are to be retained and incorporated into the Phase III cofferdam. The configuration of the Phase III cofferdam is shown in Figure 1. Each circular cell has a diameter of 63 feet consisting of 154 PS32 interlocking sheetpiles and is numbered as shown. The cells are joined by connecting arcs consisting of 78 PS32 sheet piles. The sheets vary from 95 to 105 feet in length and are embedded approximately 20 feet into the river bottom deposits. Further information and details concerning the project can be obtained by reference to the September 1988 Report.

4.0 RIVER ELEVATION/DIFFERENTIAL HEAD

During the early part of the test period the river was open, i.e., the dam tainter gates were not required to maintain the upstream navigation pool and were raised to permit free flow. River elevation at the north (upstream) cofferdam leg during this portion of the test period varied from 421.7 to 412.1 MSL NGVD. Downstream leg river elevation varied from 420.2 to 412.1 from the start of the test until July 13, 1990 on which date the gates were closed to maintain the upstream navigation pool. Downstream

leg river elevation then varied from 410.9 to 406.1. The water surface elevation in the interior of the cofferdam varied from 370.0 to 364.1 from test start until July 15, 1990. On that date an interior berm was constructed and two interior pools were formed. See Table I for river and interior pool elevations as well as differential head.

5.0 RAINFALL RECORDS

AE monitoring experience during the previous studies indicated that rainfall impact upon system sensors could result in unusually high local, short duration event rates. In order to analyze and account for this variable, the daily rainfall data collected and maintained by the Corps of Engineers was obtained and is presented in Table II.

6.0 TEST EQUIPMENT, INSTALLATION AND PROCEDURE

Acoustic emissions were monitored with a sixteen-channel PAC/ATLAS 7016/3000 computerized system manufactured by Physical Acoustics Corporation (PAC) of Lawrenceville, New Jersey. A detailed description of this unit and its operation can be found in the September 1988 Report.

The PAC/ATLAS 7016-3000 unit was installed in a cargo van which was parked on the river side of the connecting arc between cells 82 and 101. This location was selected after discussion with the Construction Contractor and in light of the limited space and congestion on the north (upstream) leg of the cofferdam. Since open river conditions prevailed, the water surface

elevation was anticipated to be close to the same as the north leg. Monitoring observations showed that there was a difference of approximately -1.8 feet between the upstream leg and the monitoring location as shown in Table I. Electric power for PAC/ATLAS operation was supplied from the project power network. Four sensors were monitored for a period of approximately four weeks during which time the last stages of unwatering proceeded. The sensors were attached to the exterior sheetpile surface of the river side of cells 80 and 81 approximately two feet below the top. Two sensors were attached to each cell and were located in plan at the approximate one-third points of the river surface of the cell. They were attached to the sheetpiles with specially fabricated magnetic holddowns to ensure sustained connection, constant mounting and contact pressure. Insofar as a visual inspection of sensor installation and location could determine, they all appeared to be identical and subject to the same hydrostatic and other AE generating conditions. Each sensor and connecting cable had a unique identification number for control purposes. Sensor location, identification, control cable identification and the PAC/ATLAS channel on which the acoustic emissions were monitored are given in Table III.

As a part of the Phase II monitoring program described in the September 1988 Report, nine waveguides were installed in cells 76, 77 and 79. These waveguides consisted of drill rods (AW) installed at varying depths in the cell fill. An attempt was made to locate and recover the waveguides so that they might

also be monitored during the unwatering procedure. Unfortunately all nine waveguides were destroyed by construction operations during the installation of the Phase III dewatering system pumping stations located in the cell 76 to 79 area. Consequently, this monitoring effort was not possible.

7.0 CONSTRUCTION ACTIVITY INTERFERENCE & EQUIPMENT MALFUNCTION

As indicated in Table IV, monitoring was inadvertently terminated several times by loss of power and/or construction activity. In addition, occasional equipment malfunctions were experienced. Data recording was interrupted three times (during Records 1, 3 and 6) by failure of all electric power on the project. The PAC/ATLAS recording cables were severed twice by construction equipment or activities. All four cables were severed during Record 4, and as a result, no data was obtained. The Channel 2 cable was severed during Record 6 with the same result, no data for that channel.

The Construction Contractor was in the process of replacing the emergency floodway bridges in the cofferdam surface roadway between cell 110 and 112, when open river conditions were terminated by gate closure. As a result, it was not possible to move the van in which the PAC/ATLAS was installed to the upstream leg of the cofferdam where differential head was the greatest.

No data was recorded on Channels 2 and 4 during Record 2 or on Channel 2 during Record 7. The data obtained in Record 5 was, in effect, a computer error message and not meaningful.

The numerical tabulation of data for Record 6 indicated that Channel 4 was in a high frequency mode when, in fact, both the sensor and the band pass filter were low frequency units.

8.0 DATA OBTAINED

The data obtained during the monitoring operation is presented in Appendices A and B. Appendix A includes numerical tabulations of events recorded on each channel and total number of counts and events for each Record. Appendix B includes continuous graphical plots of data recorded. The data generated in each Record was recorded for varying periods as shown in Table IV. As presented in Appendix B, it consists of AE events vs. time for successive 60,000 second (100 TPI) graphs. The data was monitored and recorded in 600 second (10 minute) test point intervals (TPI). All events recorded in each 600 second test point interval were accumulated and plotted as one vertical bar on the events versus time histograms. The histograms are presented in semi-logarithmic format in order to permit a clearer understanding of the data. The wide variation of events per TPI, from 0 to approximately 73,300, made it impossible to present a series of graphs at a single natural scale which would adequately represent the data. These graphs are available for inspection.

9.0 ANALYSIS AND DISCUSSION

9.1 Validity of Data

The summaries of numerical data presented in Appendix A indicate that data was obtained in Records 1, 2, 3, 6 and 7.

No data was recorded in Records 4 and 5. An inspection and review of the numerical data resulted in three elements of concern about the data retrieved; 1) the Channel Status error messages printed at the bottom of Records 1, 2, 3 and 6; 2) the discrepancy between the sum of events recorded on individual channels and the Total Low Frequency Events value in Records 1, 2 and 7 (see Table VI); and 3) the indication in Record 7 that Channel 4 was recording high frequency events.

In order to verify the validity of the data, copies of the datadisks were sent to PAC where they were read by a diagnostic program. The result of this analysis indicated that all data obtained was valid. The Channel Status error messages were generated when the disk file was not terminated properly due to power failure. This did not affect the data which had been previously written to file. The sum of the events recorded on individual channels is the correct event total. The events recorded on Channel 4 in Record 7 are high frequency events and appear to be properly listed in the file. However, since they were recorded using a low frequency sensor and band pass filter, it was considered best to disregard them in the further analysis of the results of the Study.

9.2 Variations in AE Data Recorded

Tables V and VI summarize the results of the five Records during which data was recorded in this Study. Appendix B provides a graphical plot of all Test Points recorded.

An inspection of Table V and Appendix B indicates that there is a wide variation in events per TP throughout the duration of each Record and the Study. Events per TP varied from a minimum of 0 to a maximum of 73,300. Further, the maximum recorded value of events per TP varied from 300 to 73,300. All minimum and maximum values per test point presented in Table V were scaled from natural scale graphs which are not presented.

The AE recorded on Channels 1 and 2 was approximately two to four times greater than that recorded on Channels 3 and 4, although as indicated in Section 6.0, the location, installation and hydrostatic force for each sensor appeared to be identical.

The maximum AE events per minute in Record 2 (2720 and 6480) are 25 to 35 times greater than those in Record 1 (74 to 255) although the average differential head was the same. Similarly, the maximum AE events per minute in Record 7 (6590 and 7330) are 25 to 100 times greater than those in Records 1, 3 and 6 (74 to 255), although the average differential head was seven feet less.

Finally, there appears to be substantial variation in AE recorded per TP throughout all Records. This variation seems to be more pronounced in Record 7.

Each of the foregoing variations is discussed below.

9.2.1 Comparison of Data Volume Recorded on Channels 1 & 2 Versus 3 and 4

Various changes in Sensors and cables were made in an attempt to isolate a possible equipment malfunction which might explain the difference between the volume of data recorded on

Channels 1 and 2 compared to Channels 3 and 4. The sensors recording Channels 3 and 4 were replaced after Record 2. All cables were changed after Record 4. Neither of these changes had an appreciable result insofar as modifying the relationship of number of events recorded. The Channel 4 sensor was replaced after Record 6. This Channel did not record after TP 300 in Record 7 and apparently a failure occurred in the Channel 4 circuitry at that time.

After review of the foregoing, no specific explanation is apparent for the difference between the volume of data recorded on Channels 1 and 2 versus Channels 3 and 4.

9.2.2 Comparison of Events Per Minute in Records 1, 3 & 6 Versus 2 and 7

A review of the data presented in Appendix A and summarized in Table V indicates that substantially greater AE activity was recorded in Records 2 and 7 than in Records 1, 3 and 6. Some of this activity appears to be related to construction noise and in other cases it resembles the result of a thunderstorm. For example, AE generated by construction could be recorded on one or more channels dependent upon the magnitude and location of the source. It might be expected that noise from thunderstorms should impact all active channels at the same time.

The Daily Project Construction Log was reviewed to determine if a correlation could be established between construction activity and AE records. The result of this review was inconclusive; that is, no specific activities were logged which could be

identified as causative. However, the Log did indicate that the installation of Dewatering Pump Station No. 26 was in process during the period from July 16 through July 21, 1990. The Pump Station is located on the inboard side of Cell 82 and it would be reasonable to expect this type of activity to generate substantial amounts of AE.

An inspection of Record 2 indicates substantial and consistent AE activity during normal working hours. Records 1, 3 and 6 were all recorded on weekends when construction activity would not normally be expected to occur. The AE data recorded in Record 7 is reasonably consistent with normal construction periods with some exceptions. Approximately 88% of the AE in Record 7 was recorded on Channel 3. This could be the result of construction activity in the cell 81/82 area. In any case, the construction activity discussed above was a major factor in the volume of AE generated during Records 2 and 7 as compared to 1, 3, and 6.

Thunderstorms are characterized by intense activity of short duration recorded on all active channels. As shown on Table II, the only substantial rainfall during an active Record period occurred on July 20, 21 and 22, 1990. A review of Record 7, (See Appendix B, pages B33 to B40) indicates that this rainfall/ thunderstorm activity did not substantially affect the AE generated during this period. In each case the magnitude of events per TP was not consistent on both active channels leading to the conclusion that rainfall was not the cause.

Certain other bursts of high AE activity occurred during Record 2 on June 27 from 0400 to 0600 hours and June 29 at 0600 hours; and during Record 7, on July 18 at 1400 hours, July 19 in the 0600 to 0700 hour period, at 1100 hours, and again at 2000 hours, July 20 at 1000 hours, July 21 at 0300 and 0700 hours and again at 1800 hours and July 22 at 1100 hours. This intense AE activity of short duration, sometimes recorded on one channel only, could not be correlated with either the construction or rainfall data that is presented. However, construction should not be ruled out as the explanatory source since records of construction operations over short periods of time are not maintained in sufficient detail to correlate with AE generated. Whatever the cause, the extremely high AE levels recorded during these periods contributed substantially to the total events per record discussed above.

Table VII provides a summary in which the AE generated by construction activities, thunderstorms and other unexplained sources have been deducted from the total AE recorded in order to provide approximate values of AE generated by unbalanced hydrostatic forces. The sources listed as "other" were obtained by manually counting and scaling from various tables and graphs in this and previous Reports. As a result, they should be considered general approximations, and Table VII is for order-of-magnitude comparison only.

9.3 Comparison With Previous Reports

9.3.1 Comparison With AET 204GR Data From Sept. 1988 Report

A review of Figures 8.8, 8.9 and 8.10 of the September 1986 Report indicates that AE counts/minute recorded on an AET 204GR instrument averaged approximately 35 to 40 due to a head differential of about 50 feet. Counts/minute increased to 60 to 70 as the differential head increased to 60 feet. Previous data has indicated that AE counts per event were in the range of 2 to 4, for the approximate head experienced in this Study. This would result in events per minute on the order of 10 to 20. This is consistent with the order-of-magnitude of the data presented in Table VII after allowance is made for the "other" AE activity discussed in Section 9.2.2.

A complete description of the AET 204GR unit may be found in the September 1988 Report.

9.3.2 Comparison With PAC/ATLAS Data From September 1988/ - May 1990 Reports

Table VII presents a comparison of data obtained using the PAC/ATLAS 7016/3000 unit. This data was extracted from Table 7.3 of the September 1988 Report, Table 3 of the May 1990 Report and Table V of this Report. As indicated, there is a general order-of-magnitude consistency of data versus head when a generalized correction is made for unusual activity, i.e., construction, rainfall, etc. as discussed above.

10.0 CONCLUSIONS

In general, the objectives of this Study were achieved. They are described as follows: Continuous records were obtained of acoustic emissions generated within a large cellular sheet-pile/earth structure, such as the Melvin Price Locks and Dam Phase III Cofferdam, during periods of known load variation against the cells; these records were correlated and compared with those presented in previous Reports; and the data obtained provided additional understanding of acoustic emission generation and transmission through the sheetpiles and interlocks.

Unfortunately the relatively small differential head developed during this Study permitted only a limited comparison of AE with the exceptional data obtained during the October/November 1986 period, when considerably greater hydrostatic loading was applied to the cells.

Two practical conclusions may be drawn as a result of the work described above; 1) it is essential to carefully plan and install an unattended continuously recording AE station in order to minimize interference from construction activities; this should include one sensor not connected to the sheetpiles that is exclusively assigned to "pick up" AE generated by extraneous (construction) noises; and 2) to arrange for automatic alternative temporary power as total reliance upon the main project electrical power network can result in the interruption of equipment functioning and loss of data acquisition.

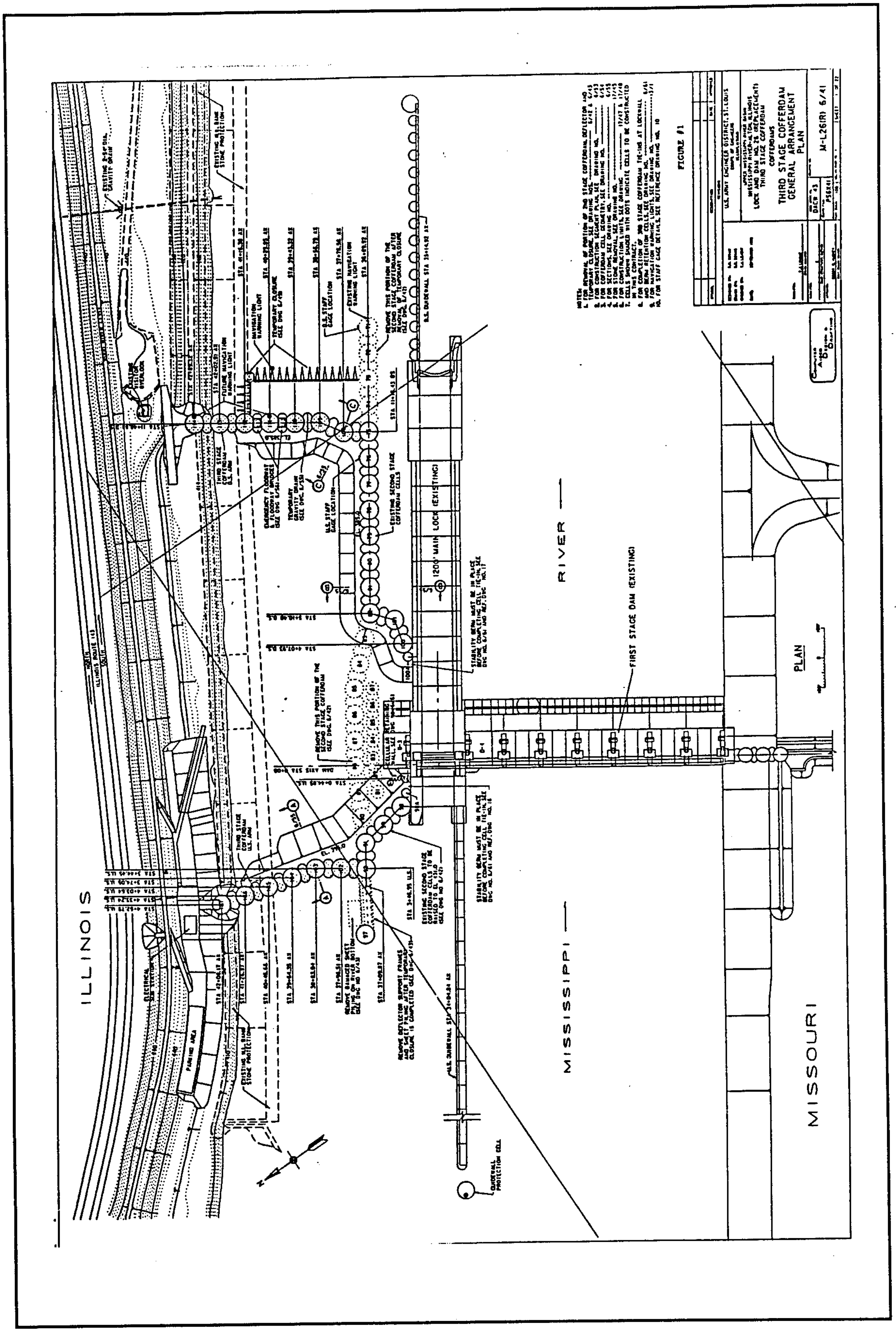

ILLINOIS
MISSISSIPPI RIVER
MISSOURI
1200' MAIN LOCK (EXISTING)
FIRST STAGE DAM (EXISTING)
PLAN
FIGURE #1
THIRD STAGE COFFERDAM
GENERAL ARRANGEMENT
PLAN
M-L26(R) 6/41

TABLE I

RIVER ELEVATION/DIFFERENTIAL HEAD
JUNE/JULY 1990

DATE	RIVER ELEV		INT POOL ELEV		DIFF	REMARKS
	UPSTREAM	DNSTREAM	UPSTREAM	DNSTREAM	HEAD	
June 22	420.6	419.2	370.9	---	48.3	Open River
23	421.7	420.2	370.9	---	49.3	
24	422.7	421.0	370.0	---	51.0	
25	422.9	421.2	370.2	---	51.0	
26	423.0	421.0	370.3	---	50.7	
27	422.7	420.9	370.9	---	50.0	
28	422.3	420.6	370.5	---	50.1	
29	421.6	420.0	370.6	---	49.4	
30	420.9	419.2	369.8	---	49.4	
July 01	420.2	418.4	369.1	---	49.3	
2	419.3	417.7	368.4	---	49.3	
3	418.6	417.0	368.7	---	48.3	
4	418.5	---	367.9	---	48.8	
5	418.1	416.4	367.4	---	49.0	
6	417.8	416.1	367.1	---	49.0	
7	417.7	415.8	366.6	---	49.2	
8	417.2	415.3	366.8	---	48.5	
9	416.1	414.5	366.0	---	48.5	
10	415.3	413.9	366.2	---	47.7	
11	414.3	413.0	366.5	---	46.5	
12	413.6	412.1	366.4	---	45.7	
13	413.2	410.9	366.1	---	44.8	Gates Closed
14	415.0	---	365.6	---	44.8	
15	415.5	409.9	364.1	366.1	43.8	Dwnstr Int Pool
16	415.7	409.2	363.9	366.0	43.2	
17	416.1	408.0	364.0	366.1	41.9	
18	416.1	407.7	363.4	366.1	41.6	
19	416.3	407.1	363.1	365.3	41.8	
20	416.6	406.6	363.3	365.2	41.4	
21	417.0	406.1	363.9	364.9	41.2	
22	416.0	407.6	363.8	364.7	42.9	
23	413.4	409.9	364.4	364.1	45.8	
24	413.6	410.5	360.7	364.0	46.5	

TABLE II

RAINFALL RECORDS
JUNE/JULY 1990

DATE	RAIN FALL (IN)	HOUR BEGIN	HOUR END	SEE APPENDIX B
June 22	---	---	---	
23	---	---	---	
24	---	---	---	
25	---	---	---	
26	---	---	---	
27	---	---	---	
28	---	---	---	
29	---	---	---	
30	---	---	---	
July 01	0.02	0300	0600	
2	---	---	---	
3	---	---	---	
4	---	---	---	
5	0.02	1900	2100	
6	0.24	1600	1700	
7	---	---	---	
8	---	---	---	
9	---	---	---	
10	---	---	---	
11	0.43	0300	0800	
12	0.41	0000	0600	
13	0.09	0000	0300	
14	---	---	---	
15	0.10	1200	1200	
16	---	---	---	
17	---	---	---	
18	---	---	---	
19	---	---	---	
20	0.98	1600	2400	Pgs. B33 - B36
21	1.10	1800	2400	Pgs. B37 - B38
22	1.54	0800	1200	Pgs. B39 - B40
23	---	---	---	
24	---	---	---	

TABLE III

CHANNEL/SENSOR/CABLE DATA

RECORD	CHAN	CELL	SENSOR	CABLE
1	1	80 S	927	40+50
	2	80 N	759	39+37
	3	81 S	757	43
	4	81 N	754	34
2	1	80 S	927	40+50
	2	80 N	759	39+37
	3	81 S	757	43
	4	81 N	754	34
3	1	80 S	927	40+50
	2	80 N	759	39+37
	3	81 S	925	43
	4	81 N	922	34
4	1	80 S	927	40+50
	2	80 N	759	39+37
	3	81 S	925	43
	4	81 N	922	34
5	1	80 S	927	40+41
	2	80 N	759	39+53
	3	81 S	925	47
	4	81 N	922	49
6	1	80 S	927	40+41
	2	80 N	759	39+53
	3	81 S	925	47
	4	81 N	922	49
7	1	80 S	927	40+41
	2	80 N	759	39+53
	3	81 S	925	47
	4	81 N	756	42

TABLE IV

TEST LOG SUMMARY

RECORD	DATE START - END	NO TEST POINTS	REMARKS
1	06/23 - 06/25	92	Aborted At TP 92. Project Power Failure.
2	06/25 - 06/29	600	No Data Recorded Channels 2 & 4.
3	06/29 - 07/03	120	Aborted At TP 120. Project Power Failure.
4	07/03 - 07/10	120	No Data Recorded. All Cables Severed At TP 120.
5	07/10 - 07/13	---	Data Garbled.
6	07/13 - 07/16	180	Aborted At TP 180. Project Power Failure. Channel 2 Cable Severed.
7	07/16 - 07/23	966	Channel 4 Indicated HF Instead Of LF.

TABLE V

TEST RESULT SUMMARY

REC	AVRG DIFF HEAD	NO TEST PNTS	CHANL	TOTAL EVENTS	EVENTS PER TEST PT AVE	EVENTS PER TEST PT MIN	EVENTS PER TEST PT MAX	EVENTS PER MINUTE AVE	EVENTS PER MINUTE MIN	EVENTS PER MINUTE MAX
1	50.2	92	1	18129	197	15	735	20	2	74
			2	15533	169	10	735	17	1	74
			3	79831	868	150	2550	87	15	255
			4	55942	608	85	1720	61	9	172
				169435	460			46		
2	50.2	600	1	179418	299	8	27200	30	1	2720
			2	**	**	**	**	**	**	**
			3	889482	1482	42	64800	148	4	6480
			4	**	**	**	**	**	**	**
				1068900	891			89		
3	49.6	120	1	4963	41	7	300	4	1	30
			2	31377	259	25	1130	26	3	113
			3	19297	159	10	620	16	1	62
			4	7447	62	5	990	6	1	99
				63084	130			13		
4	48.6	120		**	**	**	**	**	**	**
5	46.2	---		**	**	**	**	**	**	**
6	44.8	180	1	1037	6	0	540	1	0	54
			2	**	**	**	**	**	**	**
			3	10661	59	12	2450	6	1	245
			4	10810	60	0	1570	6	0	157
				22508	42			4		
7	42.9	966	1	4394507	4544	0	73300	454	0	7330
			2	**	**	**	**	**	**	**
			3	655285	678	13	65900	68	1	6590
			4	**	**	**	**	**	**	**
				5049792	2611			261		

Notes: ** Indicates No Data Recorded.

TABLE VI

COUNT/EVENT SUMMARY

REC	AVRG DIFF HEAD	NO TEST PNTS	CHANL	TOTAL EVENTS	FROM TABULAR DATA EVENTS	FROM TABULAR DATA COUNTS	CTS PER EVT
1	50.2	92	1	18129			
			2	15533			
			3	79831			
			4	55942			
				169435	113493	644054	3.8
2	50.2	600	1	179418			
			2	**			
			3	889482			
			4	**			
				1068900	1073854	3490203	3.3
3	49.6	120	1	4963			
			2	31377			
			3	19297			
			4	7447			
				63084	63084	1233777	19.6
4	48.6	120		**	**	**	**
5	46.2	---		**	**	**	**
6	44.8	180	1	1037			
			2	**			
			3	10661			
			4	10810			
				22508	22508	101480	4.5
7	42.9	966	1	4394507			
			2	**			
			3	655285			
			4	24746			
				5074538	5230453	42278430	8.3

Note: ** Indicates No Data Recorded.

TABLE VII

COMPARISON WITH OTHER REPORTS

REPORT	AVRG DIFF HEAD	HOURS	CHANLS	EVENTS		EVENTS PER MIN PER CHAN
Sept 88	45.5	1065.0	4	Total	1451346	5.7
		156.5	4	Other	1183593	31.5
		------			-------	
		908.5	4	Hydro	267753	1.2
July 89	38.0	48.0	5	Total	74487	5.2
Current						
Rec 1	50.2	15.3	4	Total	169453	46.1
Rec 2	50.2	100.0	2	Total	1068900	89.1
		2.7	2	Other	372300	1149.1

		97.3	2	Hydro	696600	59.7
Rec 3	49.6	20.0	4	Total	64495	13.4
Rec 6	44.8	31.0	3	Total	22508	4.0
Rec 7	42.9	161.0	2	Total	5074538	262.7
		28.5	2	Other	4228100	1236.3
		------			-------	
		132.5	2	Hydro	846438	53.2

APPENDIX A

TABULAR DATA; TEST POINT 1 TO FINAL TEST POINT

Test Point # 92	(Time)		FRP #	1
Time of Test Point	Start	00 00:00:00	Finish	00 15:20:00
Parametric input	Start	00	Finish	00

Cumulative Data for Test - All Hits

Low F/LT	Events	113493	Low Freq. Counts	644054
High F/HT	Events	14	High Freq. Counts	500386

Low Thres. Evnts (1-8) (9-16) Ave. / Ch. = 00 9796

18129	15533	79831	55942	00	00	00	00
00	00	00	00	00	00	00	00

High Thres. Evnts (1-8) (9-16) Ave. / Ch. = 00 01

02	162	13	14	00	00	00	00
00	00	00	00	00	00	00	00

Low Freq. Amp.(20-59 dB) (60-99 dB) Ave./Pt. = 45.7

00	21	276	17529	40761	24317	24725	3364
1042	334	142	56	79	48	06	04

High Freq. Amp.(20-59 dB) (60-99 dB) Ave./Pt.= 46.4

00	3675	733	7673	14494	9156	10320	6821
2638	655	116	10	00	01	00	01

Channel Statuseeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeee
eeeeeeeeeeeeeeeeeeeee

Record 1

Test Point # 600	(Time)		FRP #	1
Time of Test Point	Start	00 00:00:00	Finish	04 03:59:58
Parametric input	Start	00	Finish	00

Cumulative Data for Test - All Hits

Low F/LT	Events	1073854	Low Freq. Counts	3490203
High F/HT	Events	00	High Freq. Counts	00

Low Thres. Evnts (1-8) (9-16) Ave. / Ch. = 534450 00

179418	00	889482	00	00	00	00	00
00	00	00	00	00	00	00	00

High Thres. Evnts (1-8) (9-16) Ave. / Ch. = 1827 00

721	00	2934	00	00	00	00	00
00	00	00	00	00	00	00	00

Low Freq. Amp.(20-59 dB) (60-99 dB) Ave./Pt. = 6508.5

00	193	4209	262391	396648	181077	107905	54577
22154	14798	6494	406	217	100	44	29

High Freq. Amp.(20-59 dB) (60-99 dB) Ave./Pt.= 0.0

00	00	00	00	00	00	00	00
00	00	00	00	00	00	00	00

Channel Status L * L * * * * * * * * * * * * * * eph3.uuwtr 062590 1142eeeeeeeeeee
eeeeeeee

Record 2

A-1

```
        Test Point #        120    (Time)                          FRP #    1
        Time of Test Point         Start    00 00:00:00      Finish  00 20:00:00
        Parametric input           Start             00      Finish           00

        Cumulative Data for Test - All Hits

L w F/LT      Events               63084        Low Freq.  Counts           1233777
H gh F/HT     Events                  00        High Freq. Counts                00

Low   Thres. Evnts (1-8) (9-16)  Ave. / Ch.   =          00      2426
     4963      31377     19297      7447        00        00        00        00
       00         00        00        00        00        00        00        00
High Thres. Evnts (1-8) (9-16)   Ave. / Ch.   =          00        06
       05        717        60        14        00        00        00        00
       00         00        00        00        00        00        00        00
Low Freq. Amp.(20-59 dB) (60-99 dB) Ave./Pt. =         45.8
       00        435       626     13472     22819     11756      7333      3856
     1790        901       362       212       232       206       126        43
High Freq. Amp.(20-59 dB) (60-99 dB) Ave./Pt.=          0.0
       00         00        00        00        00        00        00        00
       00         00        00        00        00        00        00        00

Channel Statuseeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeee
e eeeeeeeeeeeeeeeeeeee
```

Record 3

```
        Test Point #        120    (Time)                          FRP #    1
        Time of Test Point         Start    00 00:00:00      Finish  00 20:00:00
        Parametric input           Start             00      Finish           00

        Cumulative Data for Test - All Hits

L w F/LT      Events                  00        Low Freq.  Counts                00
High F/HT     Events                  00        High Freq. Counts                00

L w  Thres. Evnts (1-8) (9-16)   Ave. / Ch.   =          00        00
       00         00        00        00        00        00        00        00
       00         00        00        00        00        00        00        00
H gh Thres. Evnts (1-8) (9-16)   Ave. / Ch.   =          00        00
       00         00        00        00        00        00        00        00
       00         00        00        00        00        00        00        00
Low Freq. Amp.(20-59 dB) (60-99 dB) Ave./Pt. =          0.0
       00         00        00        00        00        00        00        00
       00         00        00        00        00        00        00        00
High Freq. Amp.(20-59 dB) (60-99 dB) Ave./Pt.=          0.0
       00         00        00        00        00        00        00        00
       00         00        00        00        00        00        00        00

C annel Statuseeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeee
e eeeeeeeeeeeeeeeeeeee
```

Record 4

A-2

```
mp is ON                                                        11/01/90 08:53:45
t Point #      58853     (Time)                      FRP #    1
: of Test Point          Start      00 15:20:00      Finish   ut uu:uu:uu
imetric input            Start           00          Finish     -26085

ılative Data for Test - All Hits

 Events          5180090        Low Freq.  Counts             5710651
 Events          5066611        High Freq. Counts             5566983

 Evnts (1-8) (9-16)  Ave. / Ch.   =          00      62809
  74205    138684   114795     58853     58853     58853     58853
  58853     58853    58853     58853     58853     58853     58853
 Evnts (1-8) (9-16)  Ave. / Ch.   =          00      58854
  59015     58866    58867     58853     58853     58853     58853
  58853     58853    58853     58853     58853     58853     58853
 ).(20-59 dB) (60-99 dB) Ave./Pt. =          58.4
  58874     59129    76382     99614     83170     83578     62217
  59187     58995    58909     58932     58901     58859     58857
 ıp.(20-59 dB) (60-99 dB) Ave./Pt.=          59.2
  62528     59586    66526     73347     68009     69173     65674
  59508     58969    58863     58853     58854     58853     58854

  eeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeee
  eeeeeeeee
```

Record 5

```
   oint #        180     (Time)                      FRP #    1
   : Test Point          Start      00 00:00:00      Finish   01 06:00:00
   :ric input            Start        -26085         Finish         00

   ive Data for Test - All Hits

   nts            22508         Low Freq.  Counts             101480
   nts               00         High Freq. Counts                 00

   ts (1-8) (9-16)  Ave. / Ch.   =          00      1169
    00     10661    10810        00         00        00        00
    00        00       00        00         00        00        00
   .s (1-8) (9-16)  Ave. / Ch.   =          00        08
    00        82       00        00         00        00        00
    00        00       00        00         00        00        00
   0-59 dB) (60-99 dB) Ave./Pt. =          41.6
    96      3129     7746      5995       2882      1534       701
    96        74       34        05         06        01        00
   20-59 dB) (60-99 dB) Ave./Pt.=           0.0
    20        00       00        00         00        00        00
    00        00       00        00         00        00        00

   eeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeee
   eeeee
```

Record 6

```
oc oooo
```

A-3

```
        Test Point #        966    (Time)                      FRP #    1
        Time of Test Point         Start    00 00:00:00        Finish   06 16:59:56
        Parametric input           Start            00         Finish           00

        Cumulative Data for Test - All Hits

Low F/LT     Events           5230453        Low Freq.  Counts          42278430
High F/HT    Events               108        High Freq. Counts            163029

Low  Thres. Evnts (1-8) (9-16)  Ave. / Ch.  =  2524896     24746
  4394507       00   655285     24746        00        00        00        00
       00       00       00        00        00        00        00        00
High Thres. Evnts (1-8) (9-16)  Ave. / Ch.  =     5069       108
     5220       00     4919       108        00        00        00        00
       00       00       00        00        00        00        00        00
Low Freq. Amp.(20-59 dB) (60-99 dB) Ave./Pt. =      40.8
       00   149410  1208105   1669110   1134808    630805    381854    210101
    97404    42870    12629      2787       870       358       121        72
High Freq. Amp.(20-59 dB) (60-99 dB) Ave./Pt.=      44.2
       00      683     2136      6547      5718      3672      3262      1977
      771      290      113        38        12        01        00        00

Channel Status L * L H * * * * * * * * * * * *
```

Record 7

A-4

APPENDIX B

GRAPHIC DATA; 100 TEST POINT INTERVALS

i ·ARV   A-Dump is ON

I·ON-CUMULATIVE

.NTERVAL SUM

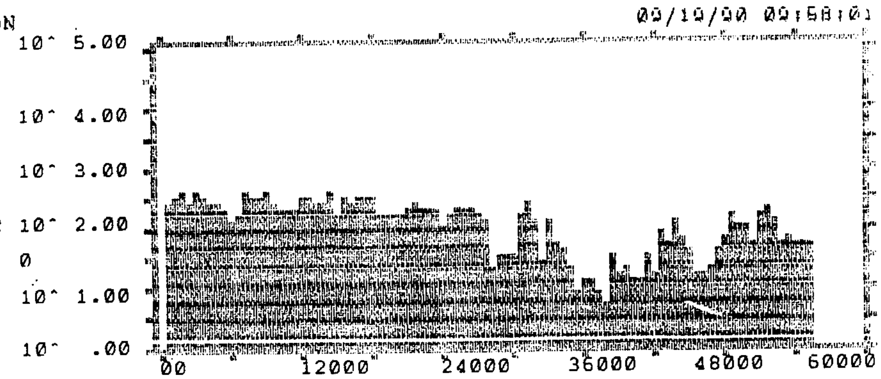
Events   LTLF

H 2

Test Point =   92

emand point =   0

GRAPH 2 OF 4



Time (Sec) LTLF CH 2

A-ARV   A-Dump is ON

NON-CUMULATIVE

INTERVAL SUM

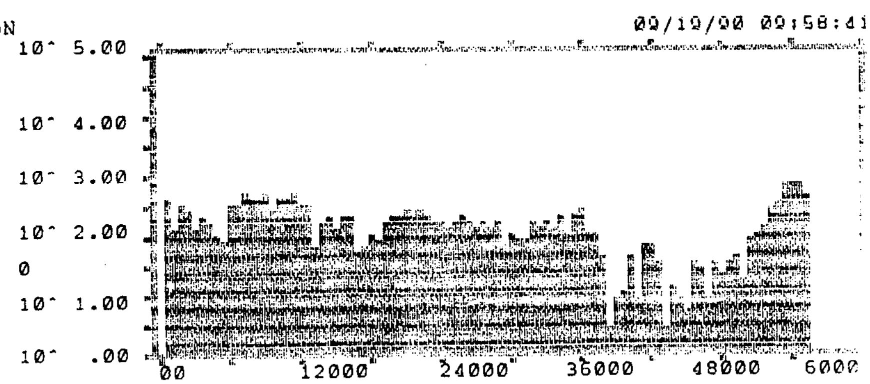
Events   LTLF

CH 1

Test Point =   92

Demand point =   0

GRAPH 1 OF 4



Time (Sec) LTLF CH 1

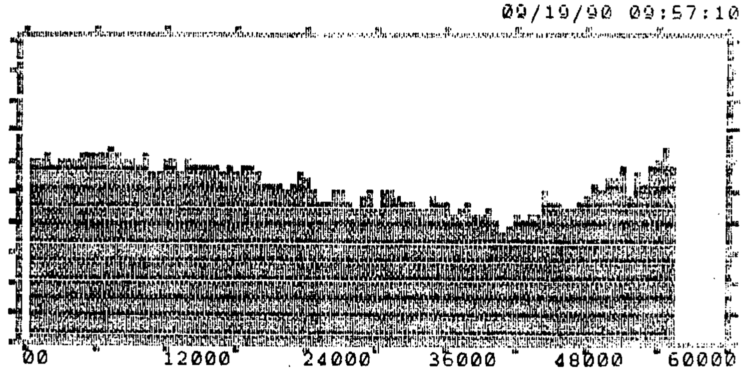
Record 1, TP 0-92

1800 Sat. 06/23 - 0920 Sun. 06/24

B-1

A=ARV A=Dump is ON 09/19/90 09:57:10

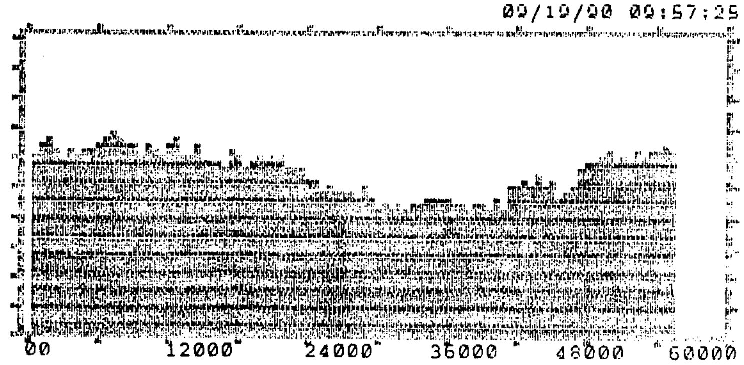
N N-CUMULATIVE 10^ 5.00
INTERVAL SUM 10^ 4.00
E ents LTLF 10^ 3.00
CH 4
T. st Point = 92 10^ 2.00
Demand point = 0
GRAPH 4 OF 4 10^ 1.00
10^ .00



Time (Sec) LTLF CH 4

.-? V A-Dump is ON 09/19/90 09:57:25

ON CUMULATIVE 10^ 5.00
NTERVAL SUM 10^ 4.00
ve-ts LTLF 10^ 3.00
H 3
est Point = 92 10^ 2.00
em. d point = 0
RAPH 3 OF 4 10^ 1.00
10^ .00



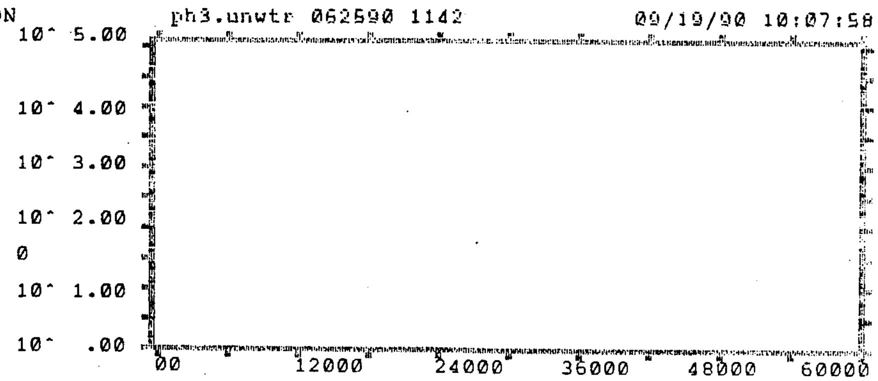
Time (Sec) LTLF CH 3

Record 1, TP 0-92

1800 Sat. 06/23 - 0920 Sun. 06/24

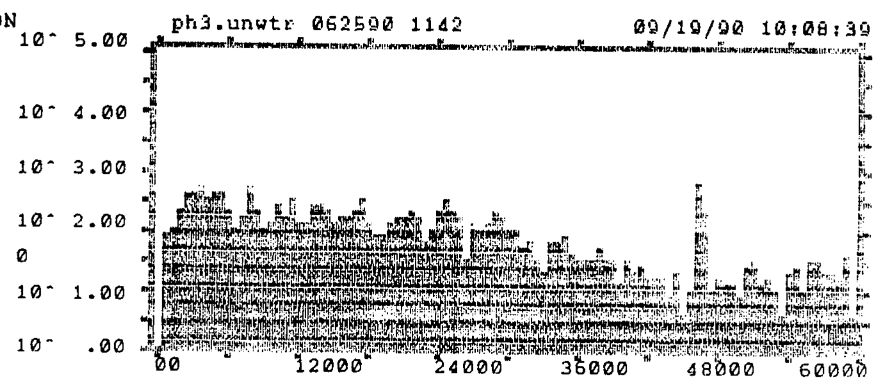
B-2

A ARV A-Dump is ON
N N-CUMULATIVE
INTERVAL SUM
E ents LTLF
C 2
Test Point = 100
D mand point = 0
GRAPH 2 OF 4



Time (Sec) LTLF CH 2

A RV A-Dump is ON
NON-CUMULATIVE
IN ERVAL SUM
Events LTLF
CH 1
Test Point = 100
De and point = 0
GRAPH 1 OF 4

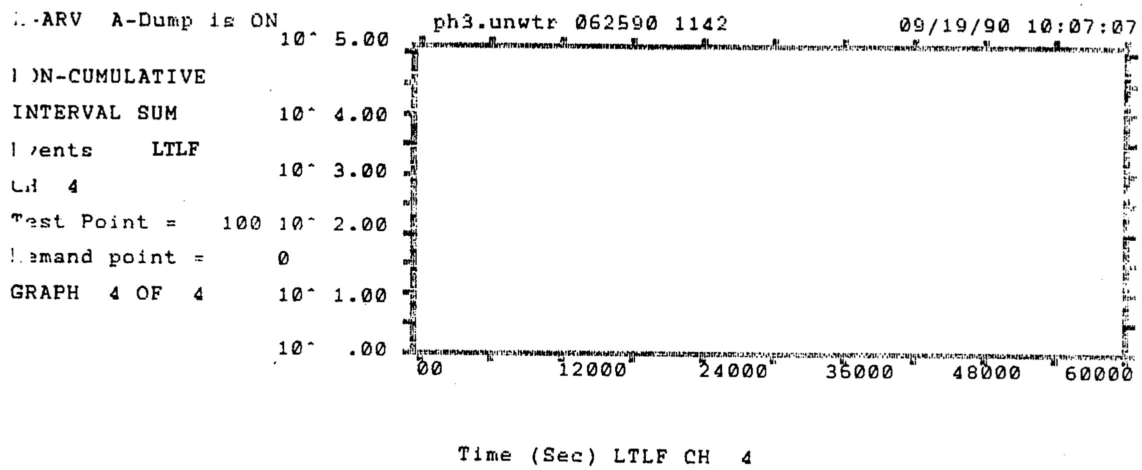


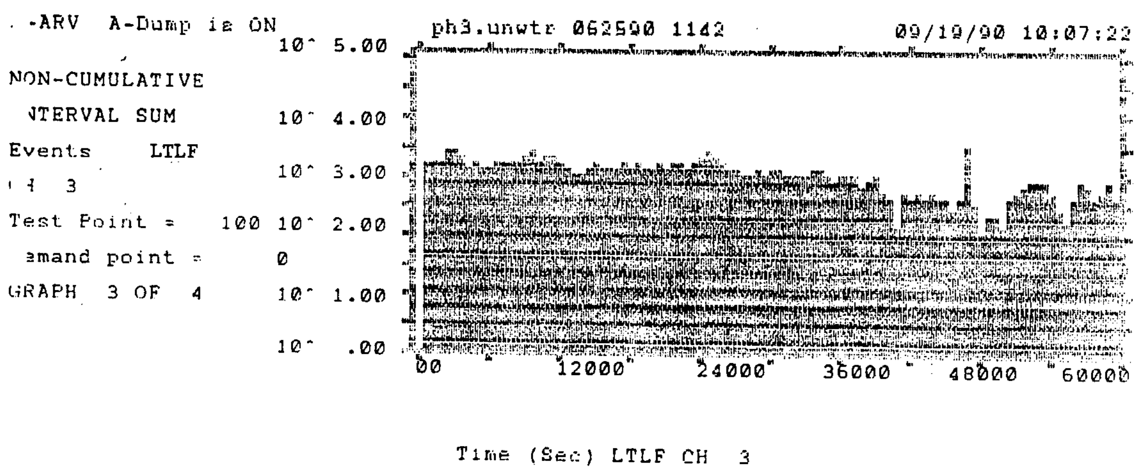
Time (Sec) LTLF CH 1

Record 2, TP 0-100

1140 Mon. 06/25 - 0420 Tues. 06/26

B-3





Record 2, TP 0-100

1140 Mon. 06/25 - 0420 Tues. 06/26

A ARV A-Dump is ON ph3.unwtr 062590 1142 09/19/90 10:14:25

N N-CUMULATIVE

INTERVAL SUM

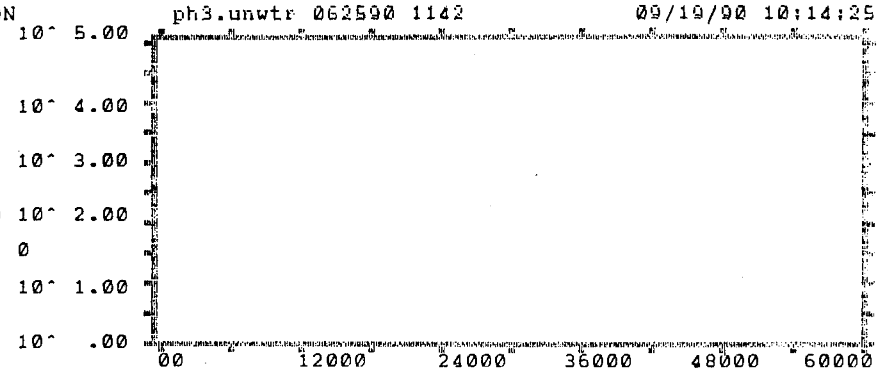
E ents LTLF

C.. 2

T=st Point = 200

D mand point = 0

GRAPH 2 OF 4



Time (Sec) LTLF CH 2

A ARV A-Dump is ON ph3.unwtr 062590 1142 09/19/90 10:15:06

NON-CUMULATIVE

I TERVAL SUM

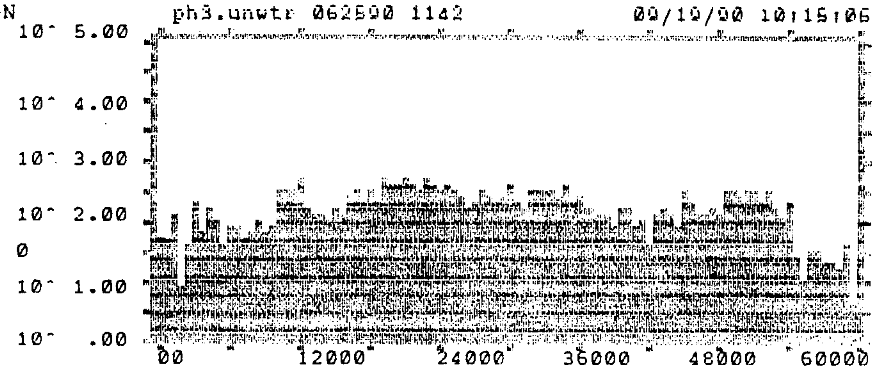
Events LTLF

C 1

Test Point = 200

D mand point = 0

GRAPH 1 OF 4



Time (Sec) LTLF CH 1

Record 2, TP 101-200

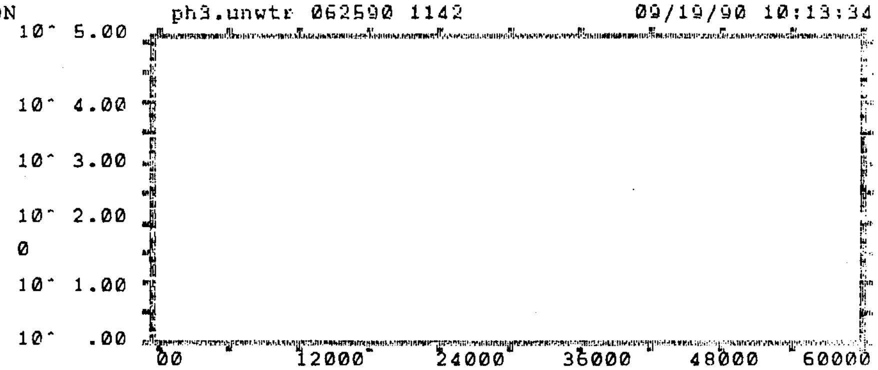
0420 Tues. 06/26 - 2100 - Tues. 06/26

B-5

A ARV A-Dump is ON

ph3.unwtr 062590 1142 09/19/90 10:13:34

N N-CUMULATIVE
INTERVAL SUM
E ents LTLF
Cn 4,
T st Point = 200
D mand point = 0
GRAPH 4 OF 4

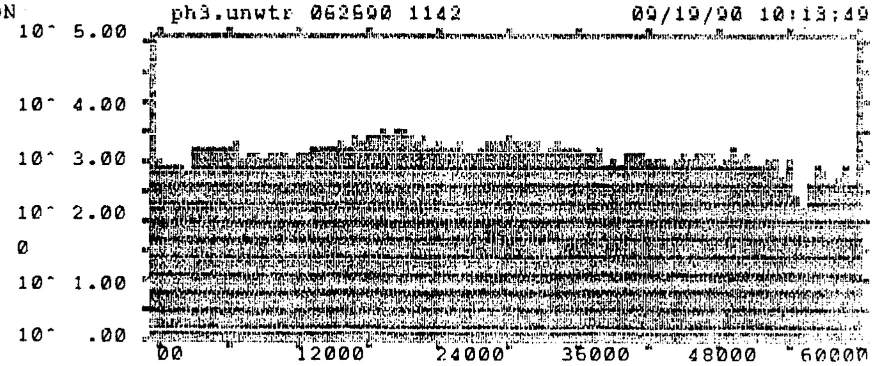


Time (Sec) LTLF CH 4

A ARV A-Dump is ON

ph3.unwtr 062590 1142 09/19/90 10:13:49

NON-CUMULATIVE
I TERVAL SUM
Events LTLF
C 3
Test Point = 200
D mand point = 0
GRAPH 3 OF 4



Time (Sec) LTLF CH 3

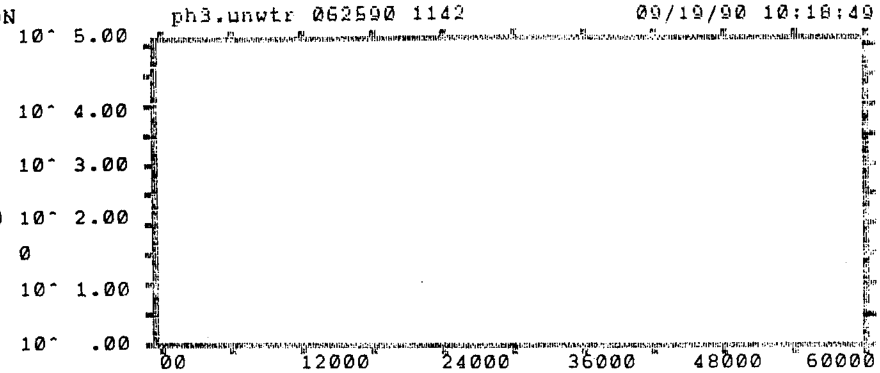
Record 2, TP 101-200

0420 Tues. 06/26 - 2100 - Tues. 06/26

B-6

A ARV A-Dump is ON ph3.unwtr 062590 1142 09/19/90 10:18:49

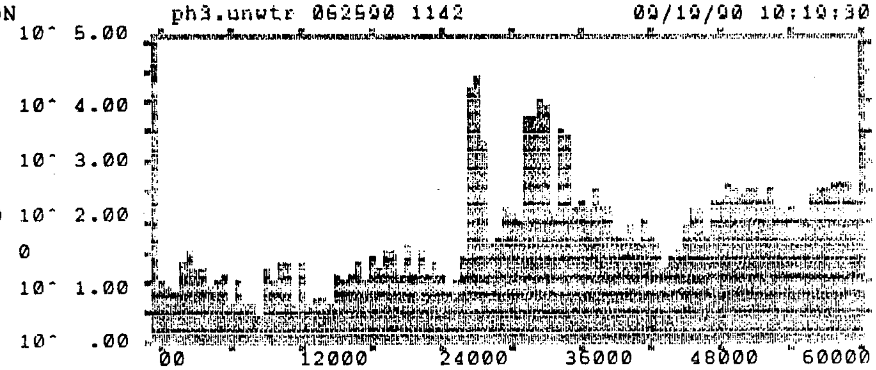
N N-CUMULATIVE
INTERVAL SUM
E ents LTLF
CH 2
Test Point = 300
D mand point = 0
GRAPH 2 OF 4



Time (Sec) LTLF CH 2

A ARV A-Dump is ON ph3.unwtr 062590 1142 09/19/90 10:19:30

NON-CUMULATIVE
INTERVAL SUM
Events LTLF
CH 1
Test Point = 300
D mand point = 0
GRAPH 1 OF 4

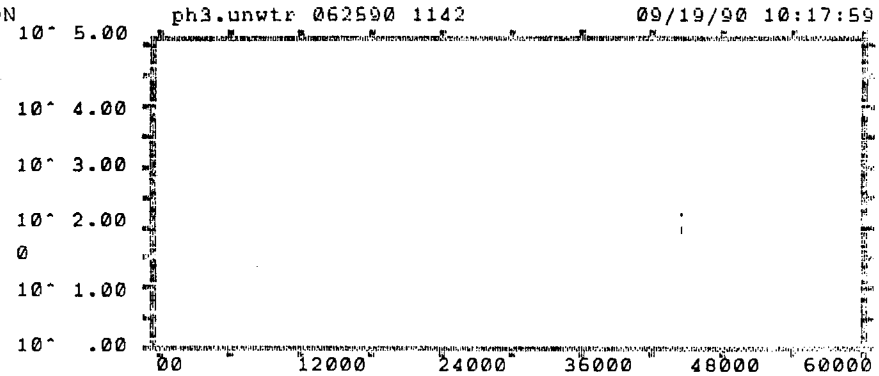


Time (Sec) LTLF CH 1

Record 2, TP 201-300
2100 Tues. 06/26 - 1340 Wed. 06/27

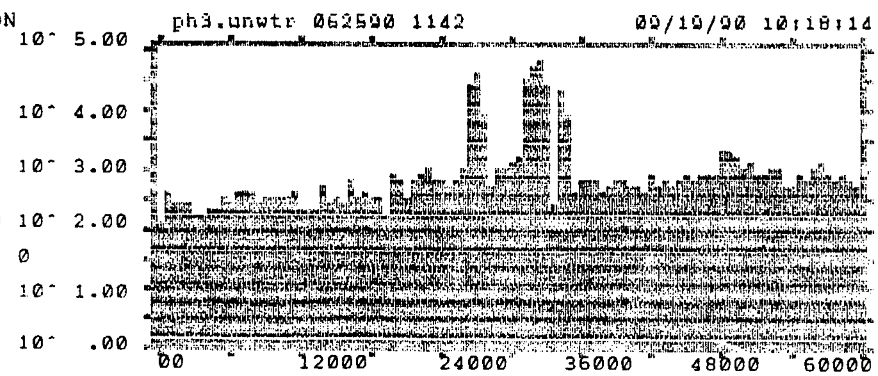
B-7

A ARV   A-Dump is ON
N N-CUMULATIVE
INTERVAL SUM
E ents   LTLF
Cn   4
T-st Point =   300
D mand point =   0
GRAPH   4 OF   4



Time (Sec) LTLF CH 4

A ARV   A-Dump is ON
NON-CUMULATIVE
I TERVAL SUM
Events   LTLF
C   3
Test Point =   300
D mand point =   0
GRAPH   3 OF   4

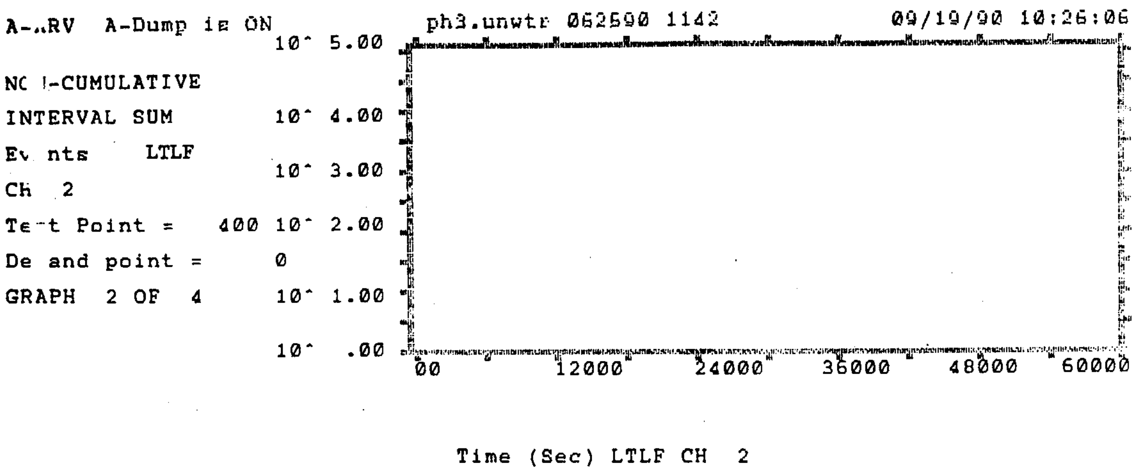


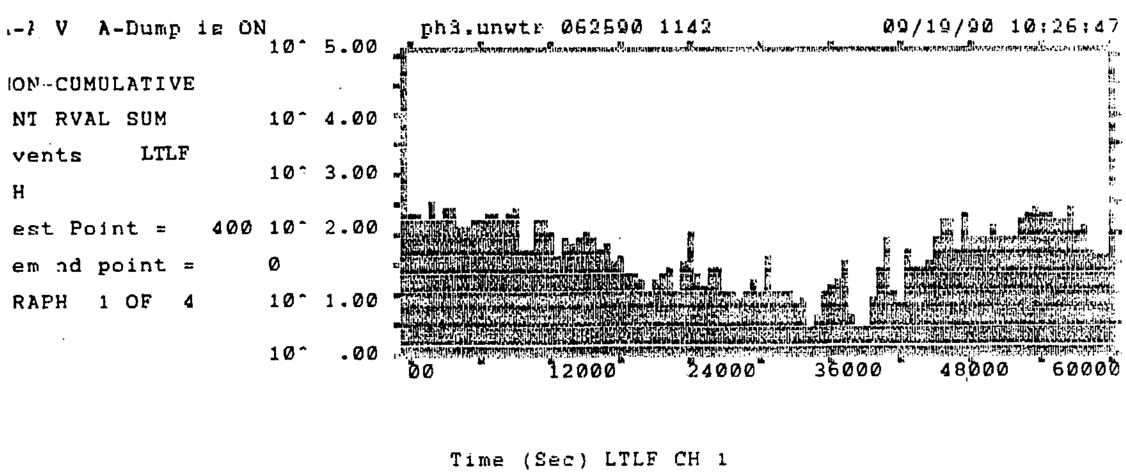
Time (Sec) LTLF CH 3

Record 2, TP 201-300

2100 Tues. 06/26 - 1340 Wed. 06/27

B-8

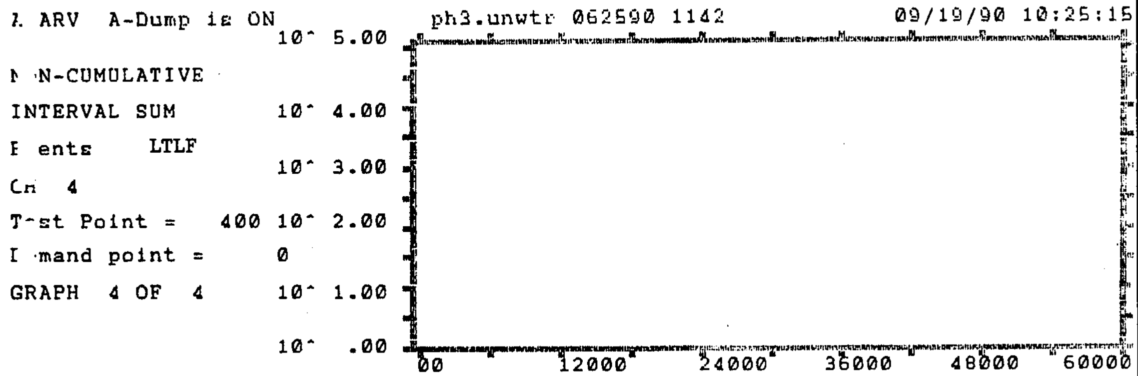




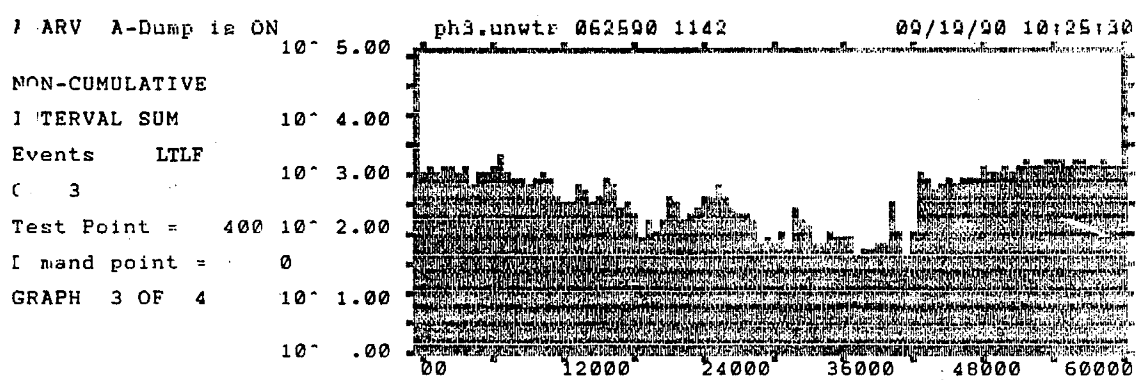
Record 2, TP 301-400

1340 Wed. 06/27 - 0620 Thur. 06/28

B-9



Time (Sec) LTLF CH 4



Time (Sec) LTLF CH 3

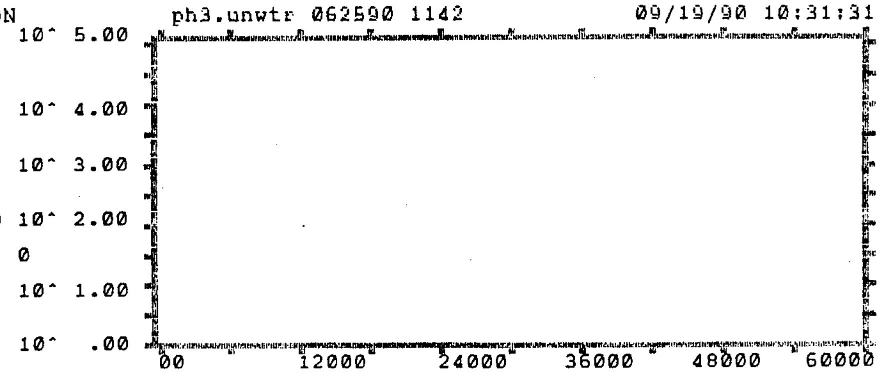
Record 2, TP 301-400

1340 Wed. 06/27 - 0620 Thur. 06/28

B-10

A ARV A-Dump is ON ph3.unwtr 062590 1142 09/19/90 10:31:31

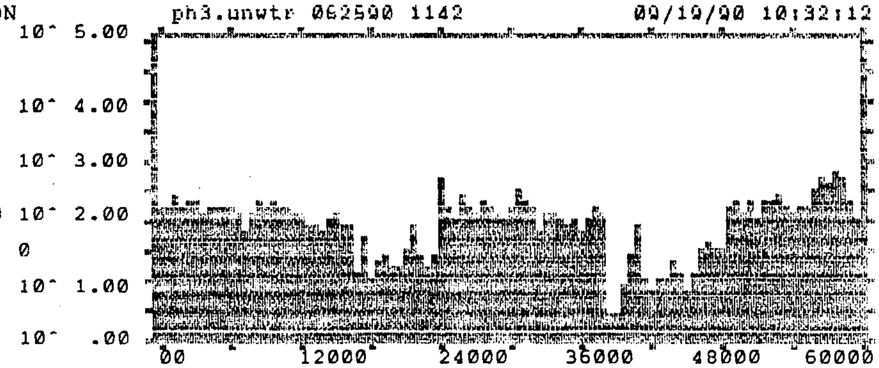
N N-CUMULATIVE
INTERVAL SUM
E ents LTLF
C.. 2
T~st Point = 500
D mand point = 0
GRAPH 2 OF 4



Time (Sec) LTLF CH 2

A ARV A-Dump is ON ph3.unwtr 062590 1142 09/19/90 10:32:12

NON-CUMULATIVE
I TERVAL SUM
Events LTLF
C 1
Test Point = 500
D mand point = 0
GRAPH 1 OF 4



Time (Sec) LTLF CH 1

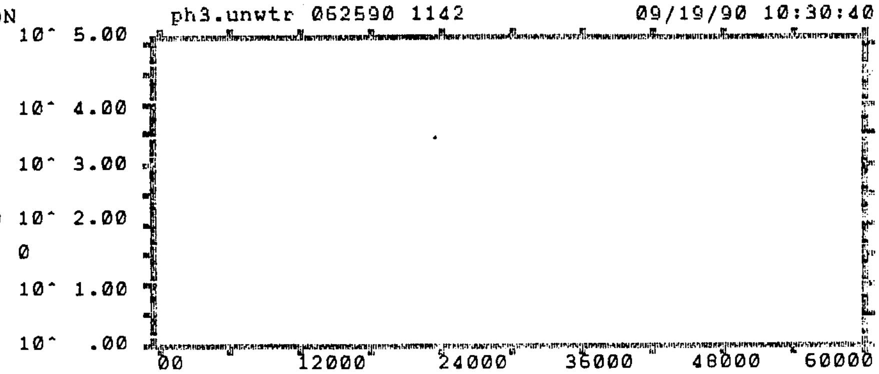
Record 2, TP 401-500

0620 Thur. 06/28 - 2300 Thur. 06/28

B-11

A ARV   A-Dump is ON   ph3.unwtr 062590 1142   09/19/90 10:30:40

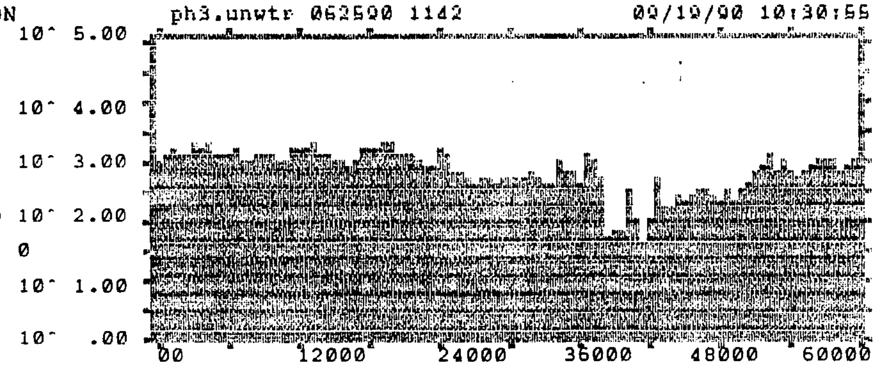
N N-CUMULATIVE
INTERVAL SUM
E ents   LTLF
Cn   4
T st Point =   500
D mand point =   0
GRAPH   4 OF   4



Time (Sec) LTLF CH   4

A ARV   A-Dump is ON   ph3.unwtr 062590 1142   09/19/90 10:30:55

NON-CUMULATIVE
I TERVAL SUM
Events   LTLF
C   3
Test Point =   500
D mand point =   0
GRAPH   3 OF   4



Time (Sec) LTLF CH   3

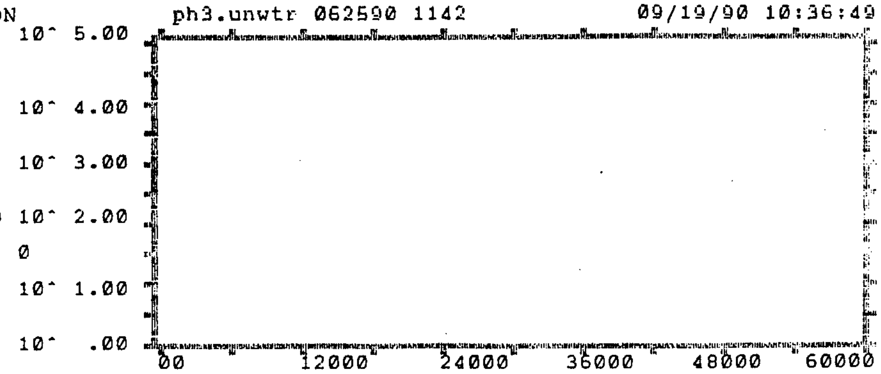
Record 2, TP 401-500

0620 Thur. 06/28 - 2300 Thur. 06/28

B-12

A-ARV A-Dump is ON ph3.unwtr 062590 1142 09/19/90 10:36:49

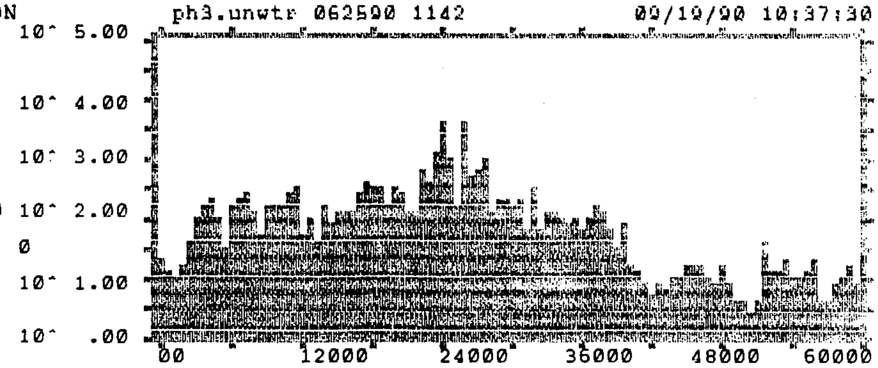
N N-CUMULATIVE
INTERVAL SUM
E ents LTLF
Cn 2
T st Point = 600
I mand point = 0
GRAPH 2 OF 4



Time (Sec) LTLF CH 2

A ARV A-Dump is ON ph3.unwtr 062590 1142 09/19/90 10:37:30

NON-CUMULATIVE
I TERVAL SUM
Events LTLF
C 1
Test Point = 600
I mand point = 0
GRAPH 1 OF 4



Time (Sec) LTLF CH 1

Record 2, TP 501-600
2300 Thur. 06/28 - 1540 Fri. 06/29

B-13

A ARV A-Dump is ON

N N-CUMULATIVE

INTERVAL SUM

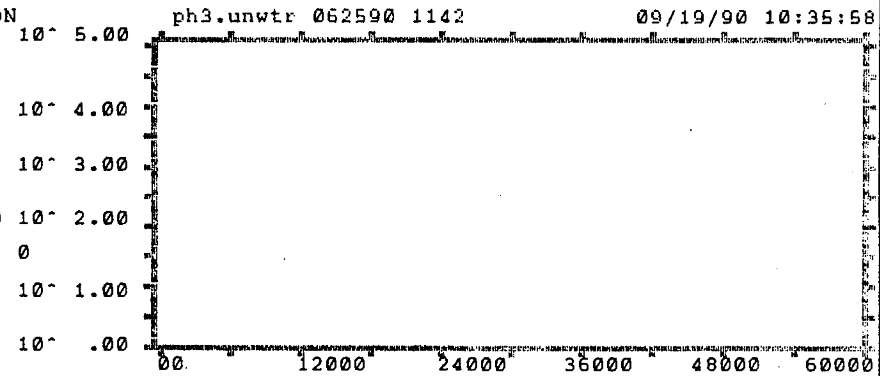
E ents LTLF

Cn 4

T^st Point = 600

D mand point = 0

GRAPH 4 OF 4



Time (Sec) LTLF CH 4

A ARV A-Dump is ON

NON-CUMULATIVE

I TERVAL SUM

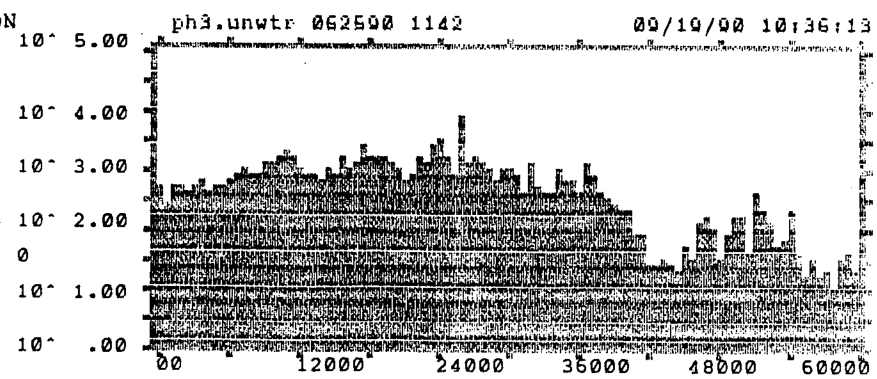
Events LTLF

C 3

Test Point = 600

D mand point = 0

GRAPH 3 OF 4



Time (Sec) LTLF CH 3

Record 2, TP 501-600

2300 Thur. 06/28 - 1540 Fri. 06/29

B-14

A ARV A-Dump is ON

N N-CUMULATIVE

INTERVAL SUM

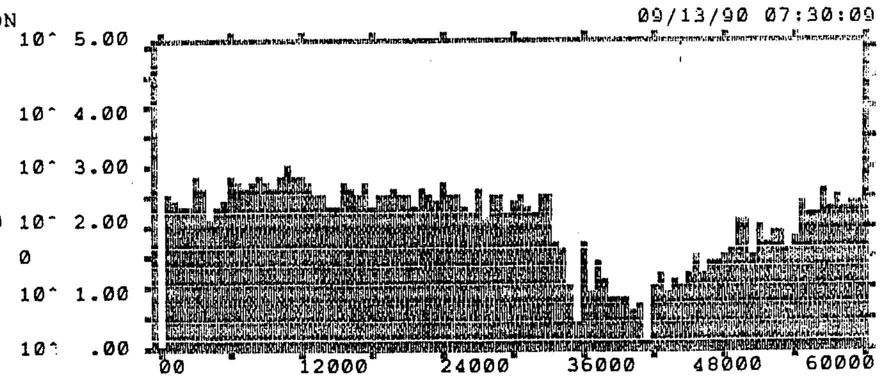
E ents LTLF

C.. 2

Test Point = 100

D mand point = 0

GRAPH 2 OF 4



Time (Sec) LTLF CH 2

A ARV A-Dump is ON

NON-CUMULATIVE

I TERVAL SUM

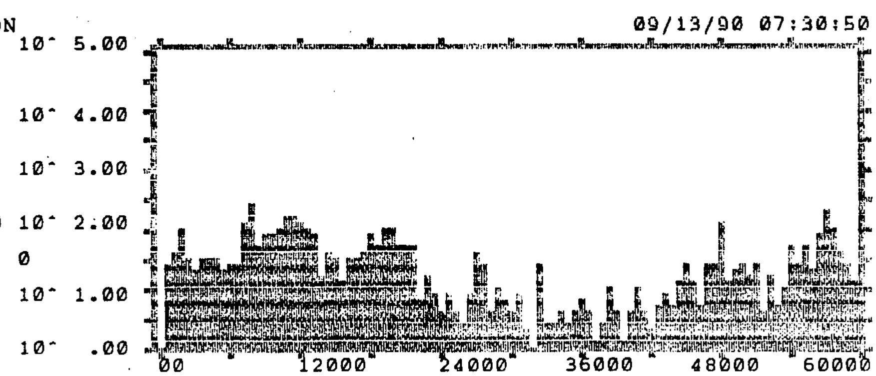
Events LTLF

C 1

Test Point = 100

D mand point = 0

GRAPH 1 OF 4



Time (Sec) LTLF CH 1

Record 3, TP 0-100

1620 Fri. 06/29 - 0900 Sat.06/30

B-15

A. ARV A-Dump is ON

NON-CUMULATIVE

INTERVAL SUM

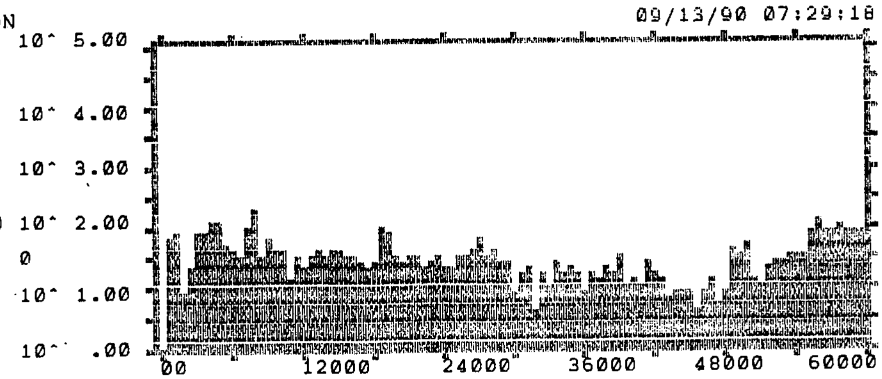
Events LTLF

CH 4

Test Point = 100

Demand point = 0

GRAPH 4 OF 4



Time (Sec) LTLF CH 4

A. ARV A-Dump is ON

NON-CUMULATIVE

INTERVAL SUM

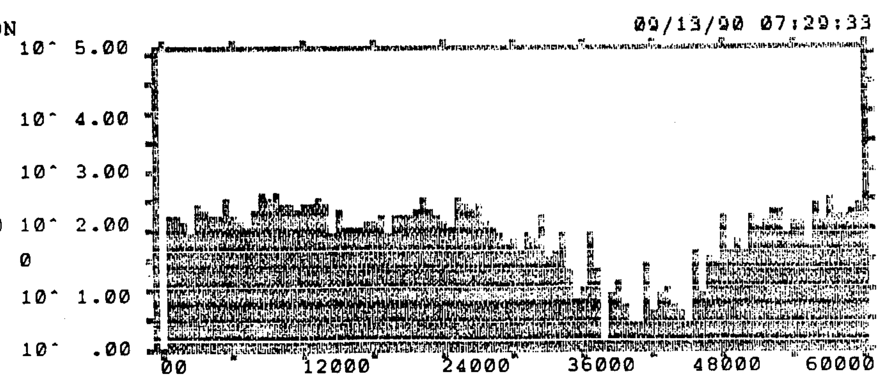
Events LTLF

CH 3

Test Point = 100

Demand point = 0

GRAPH 3 OF 4

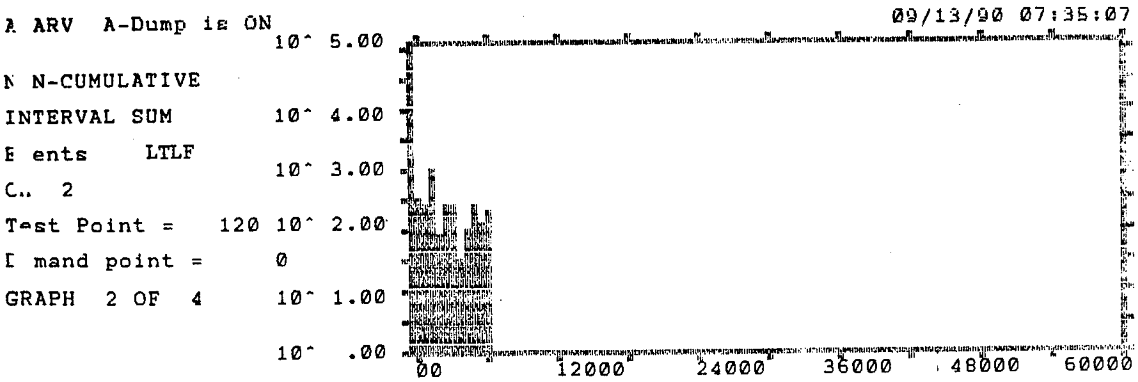


Time (Sec) LTLF CH 3

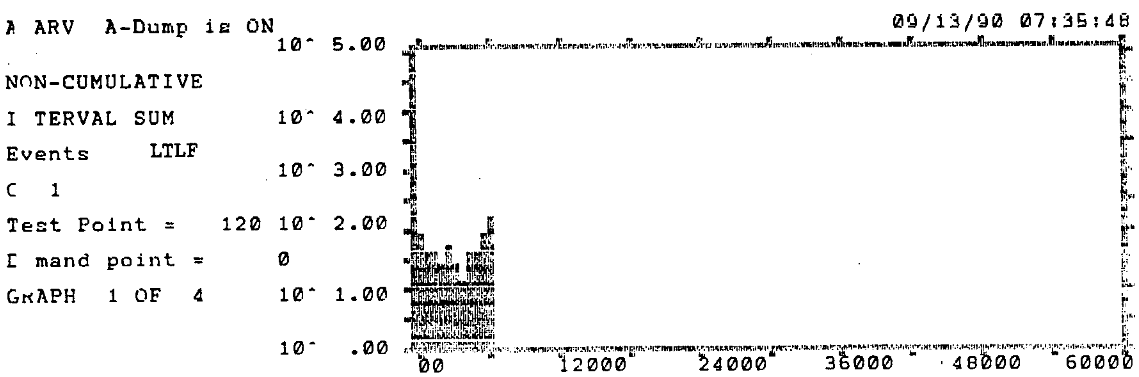
Record 3, TP 0-100

1620 Fri. 06/29 - 0900 Sat. 06/30

B-16



Time (Sec) LTLF CH 2

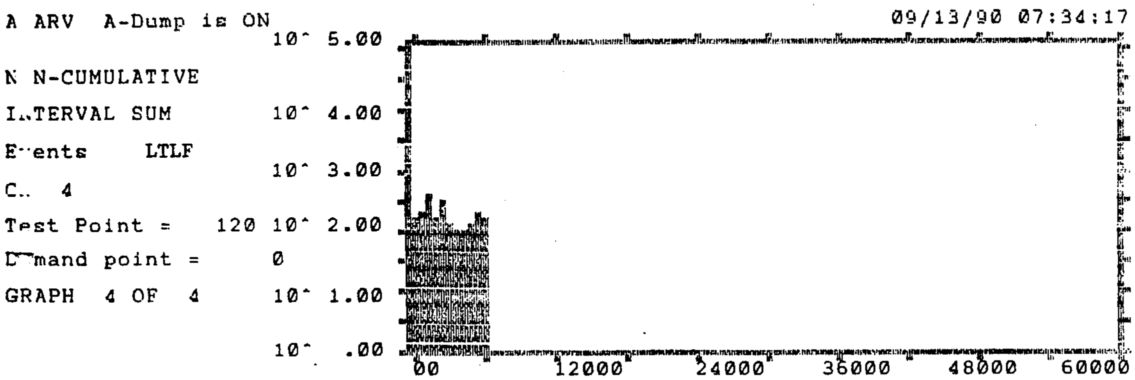


Time (Sec) LTLF CH 1

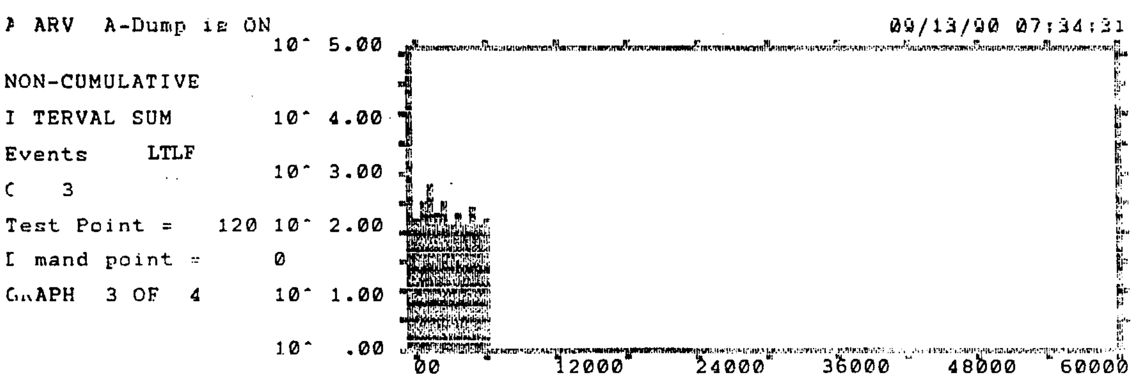
Record 3, TP 100-120

0900 Sat. 06/30 - 1220 Sat. 06/30

B-17



Time (Sec) LTLF CH 4



Time (Sec) LTLF CH 3

Record 3, TP 100-120

0900 Sat. 06/30 - 1220 Sat. 06/30

B-18

I ARV A-Dump is ON 09/13/90 07:45:03

N N-CUMULATIVE

INTERVAL SUM

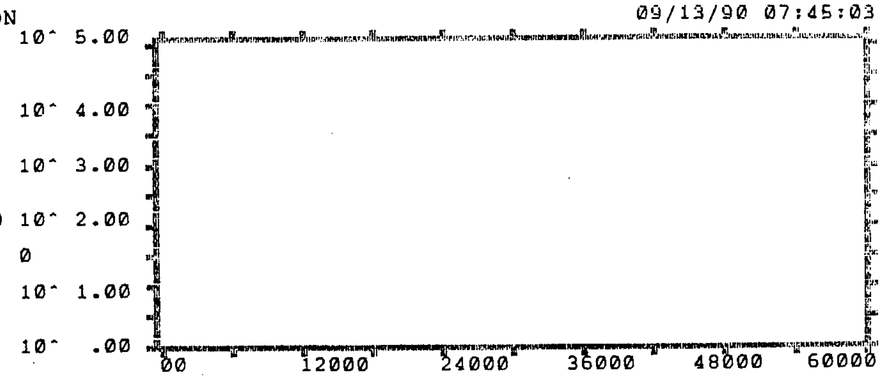
E ents LTLF

Cn 2

T-st Point = 100

I mand point = 0

GRAPH 2 OF 4



Time (Sec) LTLF CH 2

I ARV A-Dump is ON 09/13/90 07:45:44

NON-CUMULATIVE

I TERVAL SUM

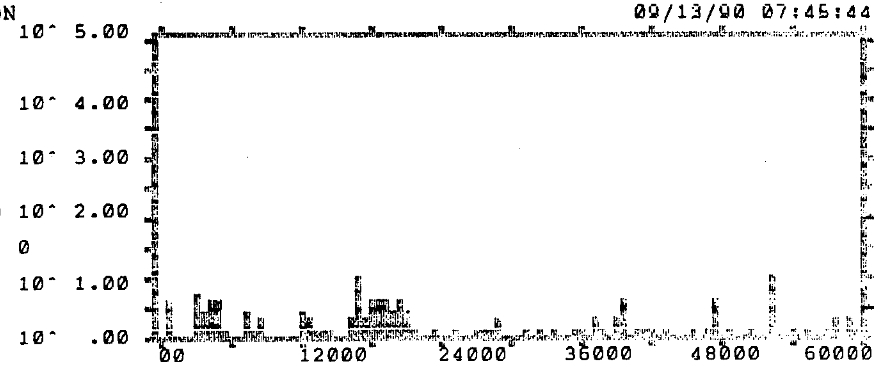
Events LTLF

C 1

Test Point = 100

I mand point = 0

GRAPH 1 OF 4

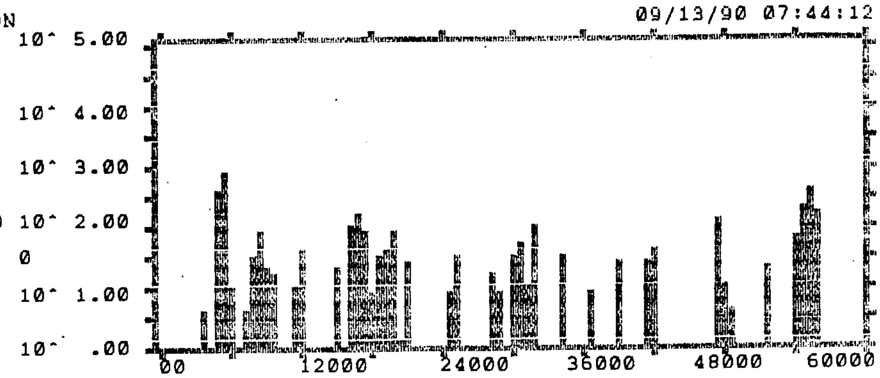


Time (Sec) LTLF CH 1

Record 6, TP 0-100

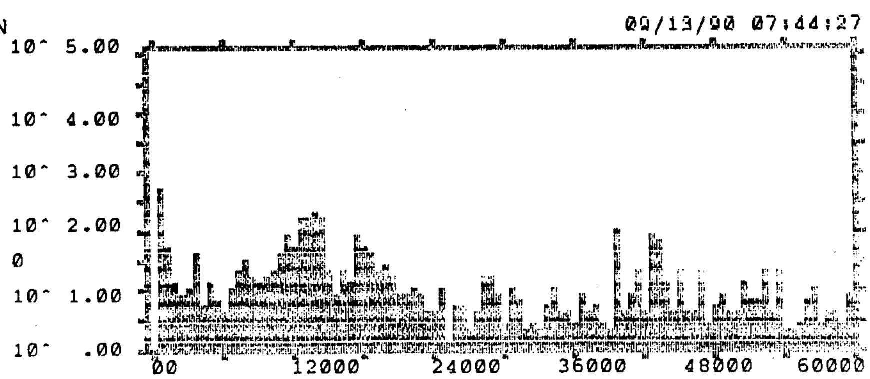
1925 Fri. 07/13 - 1205 Sat. 07/14

A ARV   A-Dump is ON
N N-CUMULATIVE
INTERVAL SUM
E ents   LTLF
C.. 4
T^st Point =   100
D mand point =   0
GRAPH 4 OF 4



Time (Sec) LTLF CH 4

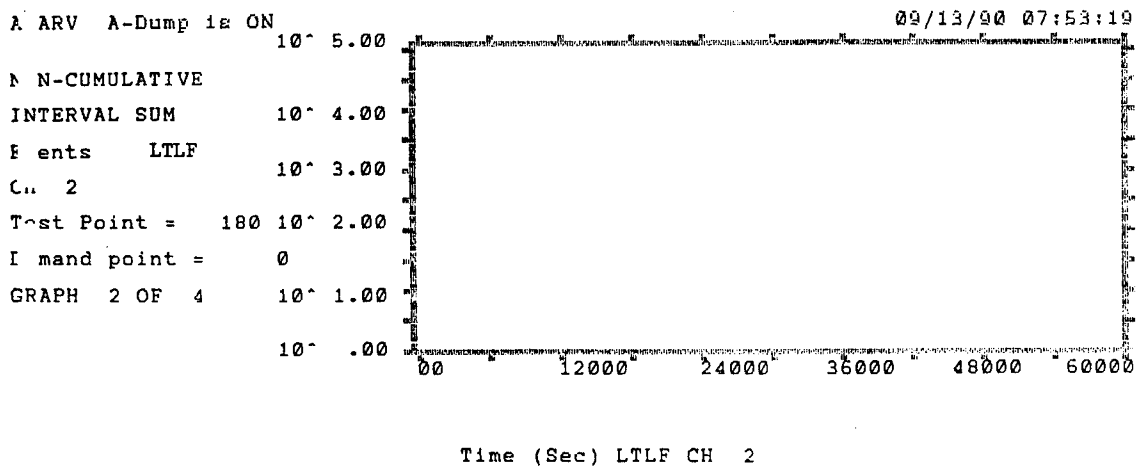
A ARV   A-Dump is ON
N^N-CUMULATIVE
I TERVAL SUM
Events   LTLF
C   3
Test Point =   100
C mand point =   0
GRAPH 3 OF 4

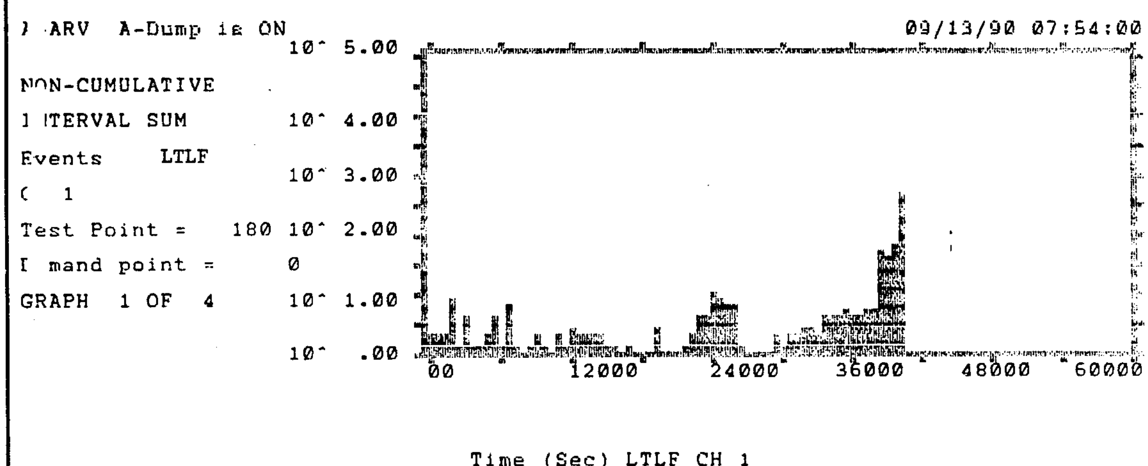


Time (Sec) LTLF CH 3

Record 6, TP 0-100
1925 Fri. 07/13 - 1205 Sat. 07/14

B-20

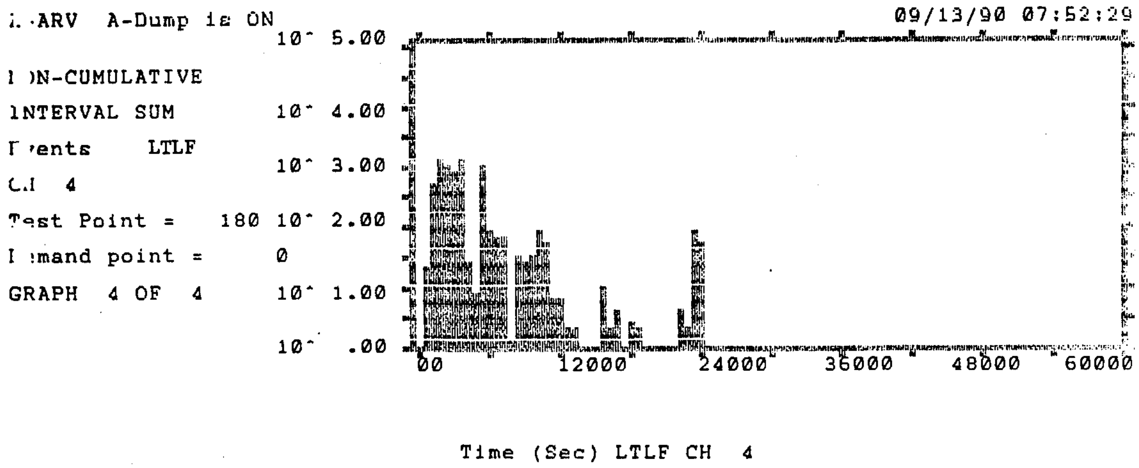


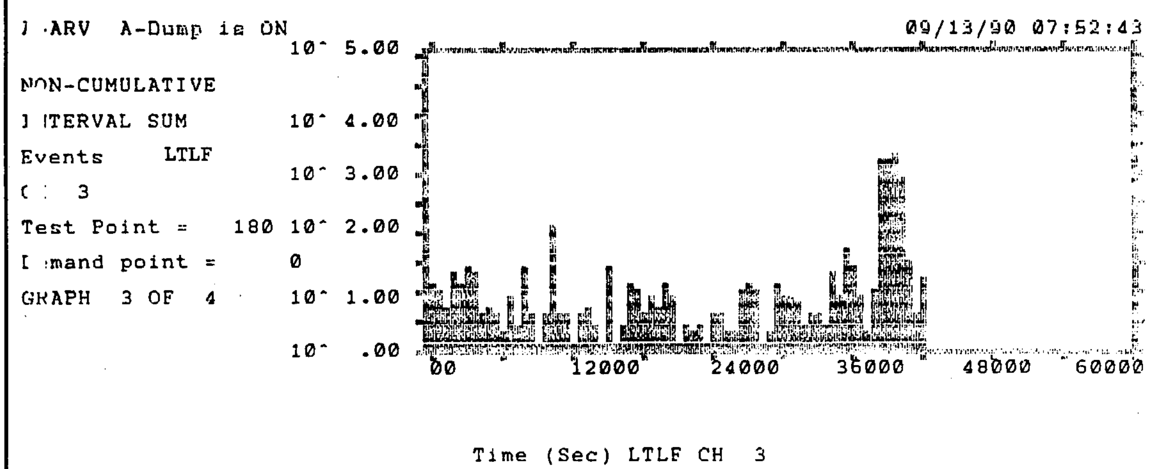


Record 6, TP 100-180

1205 Sat. 07/14 - 0125 Sun. 07/15

B-21





Record 6, TP 100-180

1205 Sat. 07/14 - 0125 Sun. 07/15

B-22

A.ARV A-Dump is ON

N.N-CUMULATIVE

INTERVAL SUM

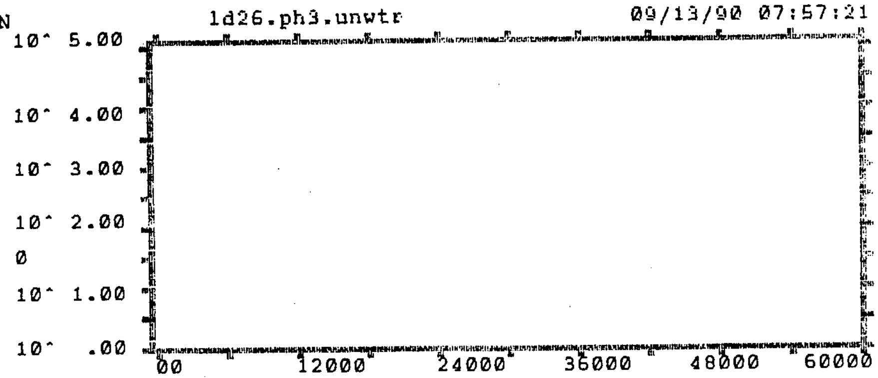
E ents LTLF

C.. 2

Test Point = 100

D mand point = 0

GRAPH 2 OF 4



Time (Sec) LTLF CH 2

A \RV A-Dump is ON

NON-CUMULATIVE

I1 :ERVAL SUM

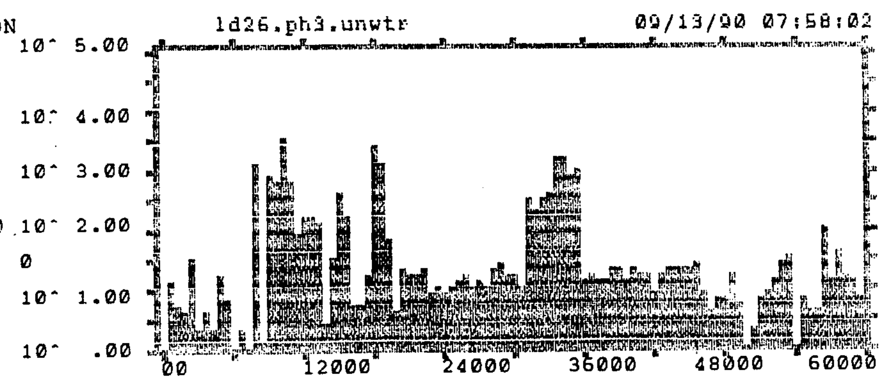
Events LTLF

CI 1

Test Point = 100

De and point = 0

GRAPH 1 OF 4

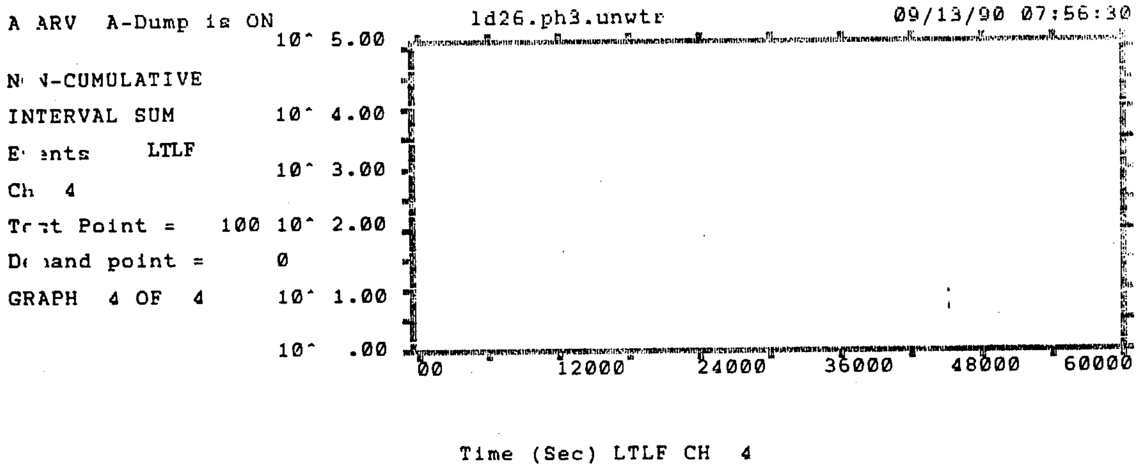


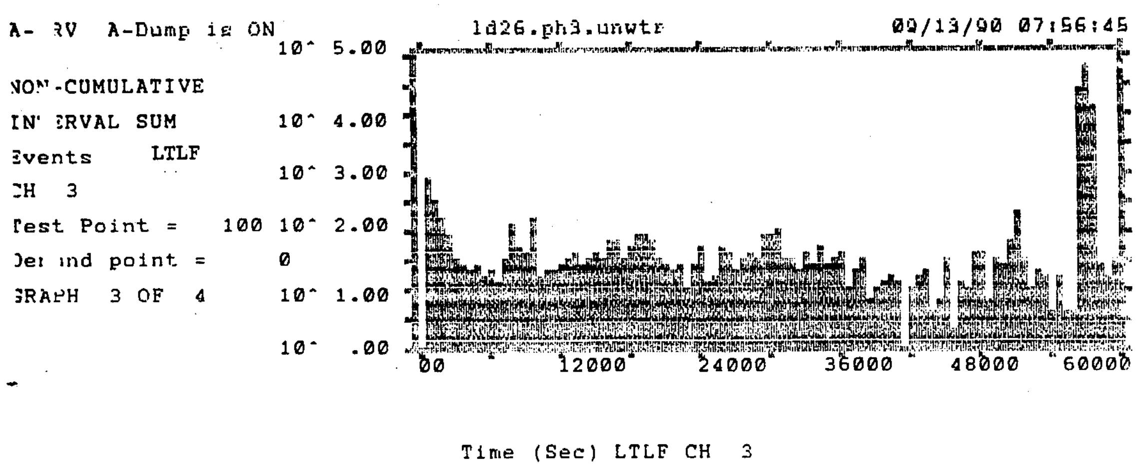
Time (Sec) LTLF CH 1

Record 7, TP 0-100

1440 Mon. 07/16 - 0720 Tues. 07/17

B-23





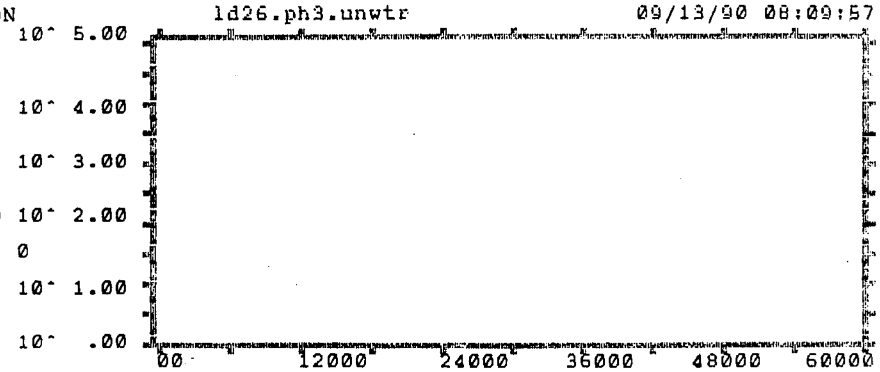
Record 7, TP 0-100

1440 Mon. 07/16 - 0720 Tues. 07/17

B-24

A ARV A-Dump is ON 1d26.ph3.unwtr 09/13/90 08:09:57

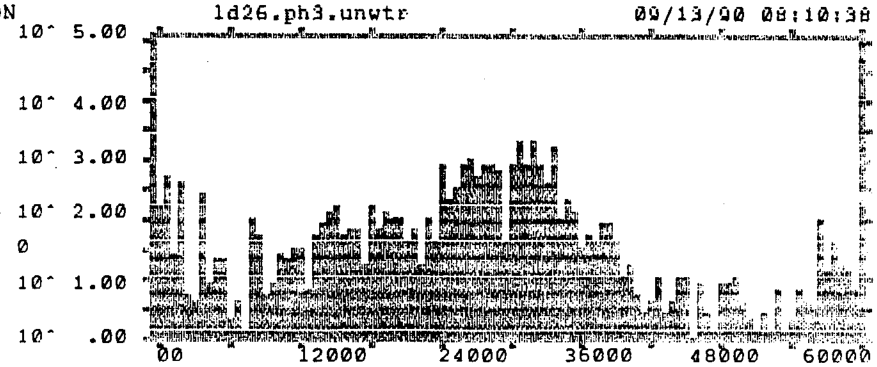
N N-CUMULATIVE
INTERVAL SUM
E ents LTLF
C.. 2
T^st Point = 200
I mand point = 0
GRAPH 2 OF 4



Time (Sec) LTLF CH 2

) ARV A-Dump is ON 1d26.ph3.unwtr 09/13/90 08:10:38

NON-CUMULATIVE
I TERVAL SUM
Events LTLF
(1
Test Point = 200
I mand point = 0
GRAPH 1 OF 4

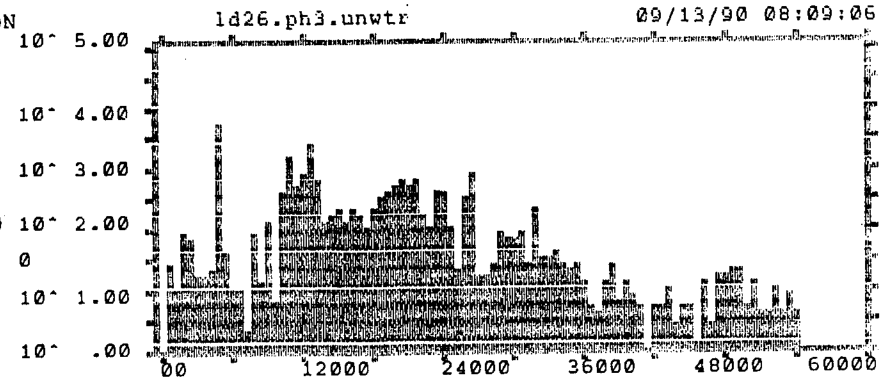


Time (Sec) LTLF CH 1

Record 7, TP 101-200
0720 Tues. 07/17 - 2400 Tues. 07/17

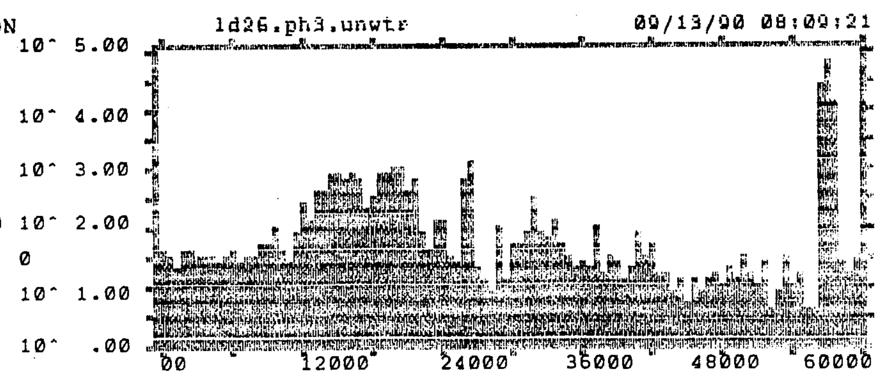
B-25

A ARV A-Dump is ON
NON-CUMULATIVE
INTERVAL SUM
Events LTLF
Ch 4
Test Point = 200
Demand point = 0
GRAPH 4 OF 4



Time (Sec) LTLF CH 4

-A V A-Dump is ON
ON-CUMULATIVE
NTERVAL SUM
vents LTLF
est Point = 200
mand point = 0
APH 3 OF 4



Time (Sec) LTLF CH 3

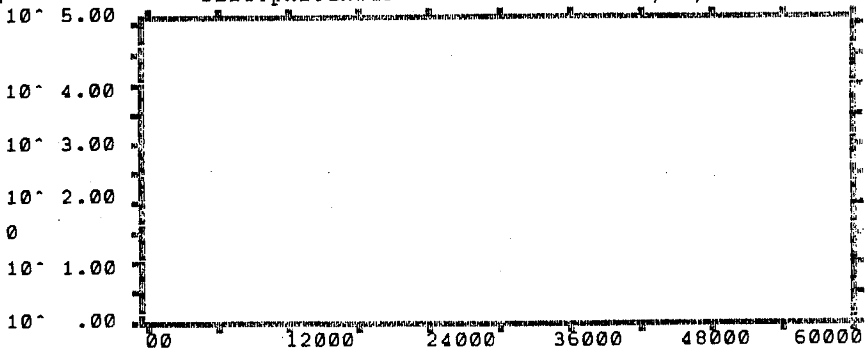
Record 7, TP 101-200

0720 Tues. 07/17 - 2400 Tues. 07/17

B-26

A-ARV A-Dump is ON 1d26.ph3.unwtr 09/13/90 08:18:48

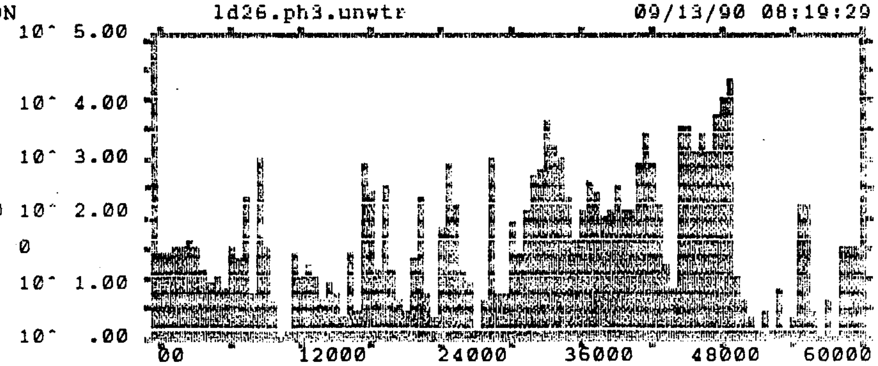
N N-CUMULATIVE
INTERVAL SUM
E ents LTLF
CH 2
T st Point = 300
I mand point = 0
GRAPH 2 OF 4



Time (Sec) LTLF CH 2

I ARV A-Dump is ON 1d26.ph3.unwtr 09/13/90 08:19:29

NON-CUMULATIVE
I TERVAL SUM
Events LTLF
C I 1
Test Point = 300
I mand point = 0
GRAPH 1 OF 4



Time (Sec) LTLF CH 1

Record 7, TP 201-300

0000 Wed. 07/18 - 1640 Wed. 07/18

B-27

A ARV A-Dump is ON 1d26.ph3.unwtr 09/13/90 08:17:57

N· N-CUMULATIVE

INTERVAL SUM

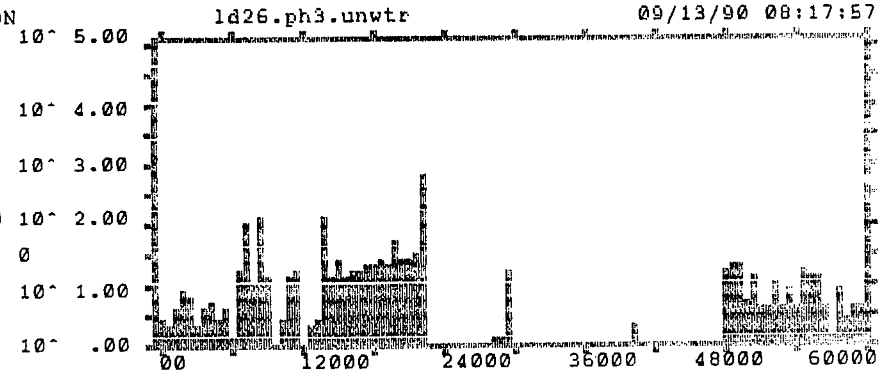
E· ents LTLF

Cl· 4

Te·t Point = 300

De ·and point = 0

GRAPH 4 OF 4



Time (Sec) LTLF CH 4

-A V A-Dump is ON 1d26.ph3.unwtr 09/13/90 08:18:12

ON CUMULATIVE

NT RVAL SUM

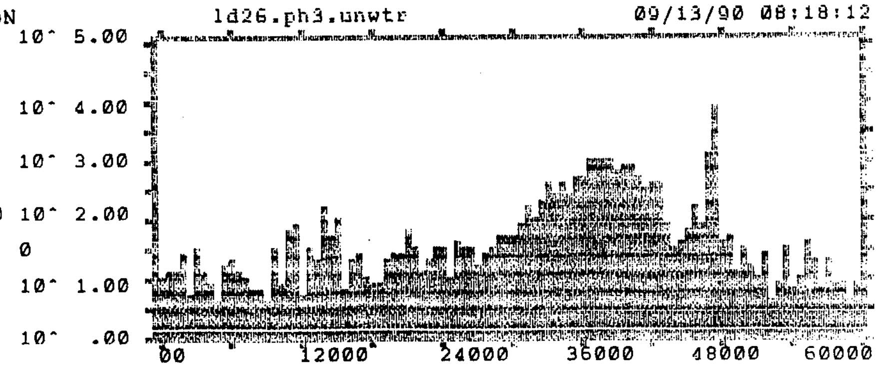
vents LTLF

H 3

est Point = 300

em. ıd point = 0

RAPH 3 OF 4



Time (Sec) LTLF CH 3

Record 7, TP 201-300

0000 Wed. 07/18 - 1640 Wed. 07/18

B-28

A ARV A-Dump is ON

N N-CUMULATIVE

INTERVAL SUM

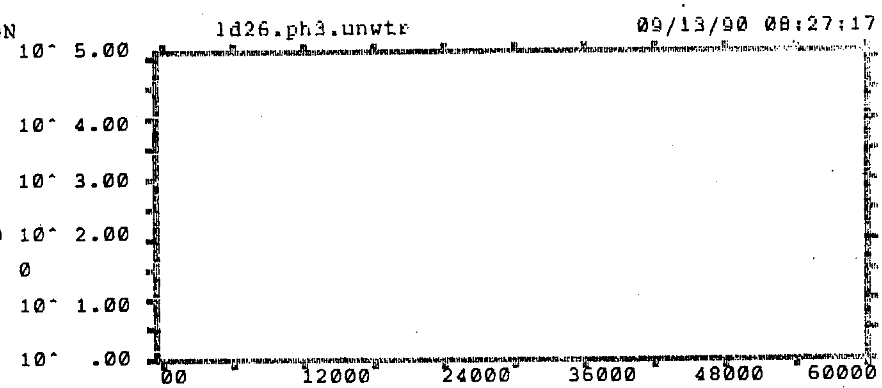
E ents LTLF

Ch 2

Test Point = 400

De and point = 0

GRAPH 2 OF 4



Time (Sec) LTLF CH 2

A- RV A-Dump is ON

NON-CUMULATIVE

IN ERVAL SUM

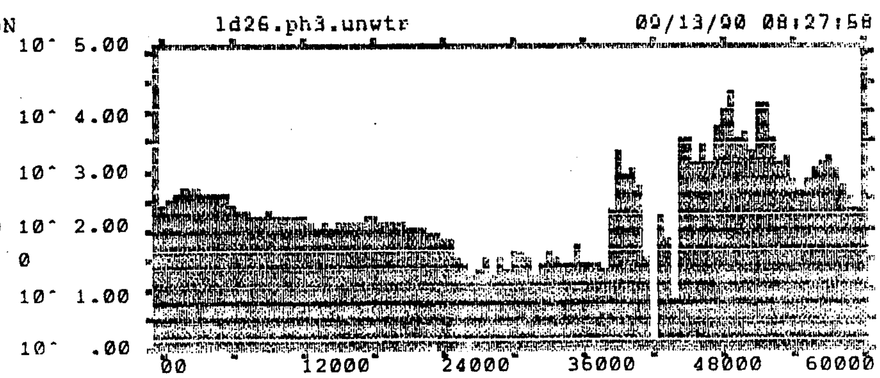
Events LTLF

CH 1

Test Point = 400

De and point = 0

GRAPH 1 OF 4



Time (Sec) LTLF CH 1

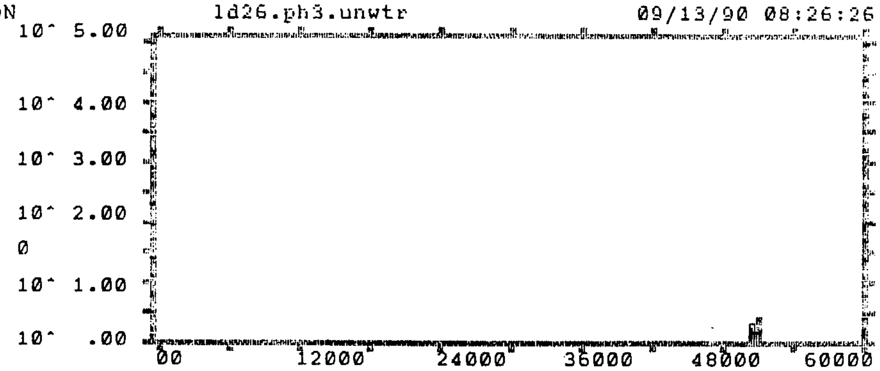
Record 7, TP 301-400

1640 Wed. 07/18 - 0920 Thurs. 07/19

B-29

A ARV A-Dump is ON 1d26.ph3.unwtr 09/13/90 08:26:26

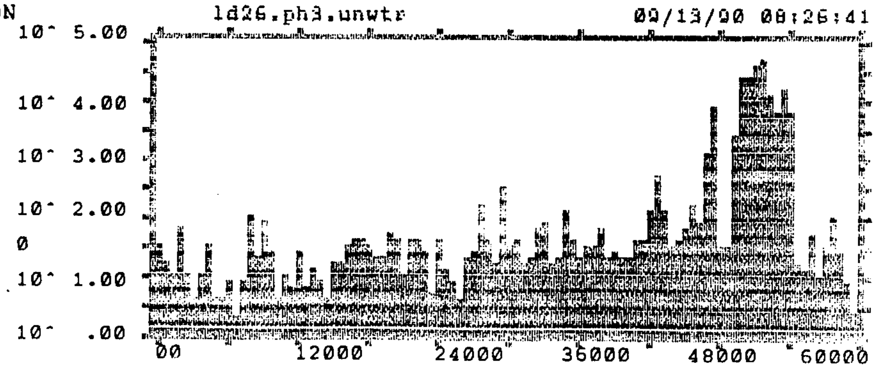
N(J-CUMULATIVE
INTERVAL SUM
E' :nts LTLF
Ch 4
Te:t Point = 400
De iand point = 0
GRAPH 4 OF 4



Time (Sec) LTLF CH 4

\-) :V A-Dump is ON 1d26.ph3.unwtr 09/13/90 08:26:41

ION-CUMULATIVE
NI RVAL SUM
:vents LTLF
'H 3
est Point = 400
em nd point = 0
RAPH 3 OF 4



Time (Sec) LTLF CH 3

Record 7, TP 301-400

1640 Wed. 07/18 - 0920 Thurs. 07/19

A ARV A-Dump is ON

N N-CUMULATIVE

INTERVAL SUM

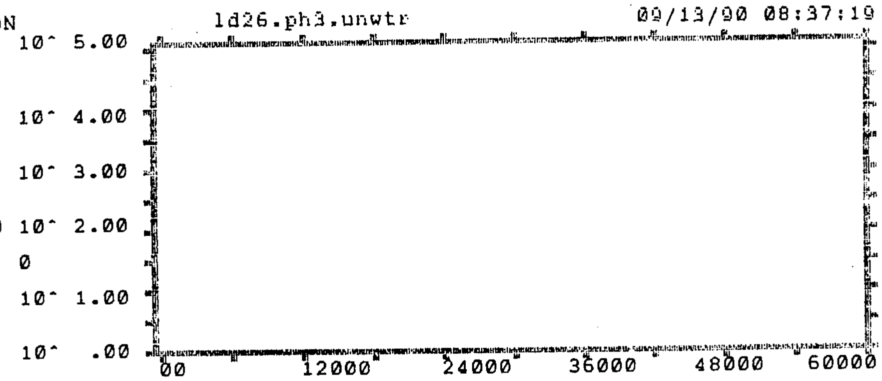
E ents LTLF

Cn 2

T-st Point = 500

D mand point = 0

GRAPH 2 OF 4



Time (Sec) LTLF CH 2

A ARV A-Dump is ON

N^N-CUMULATIVE

I TERVAL SUM

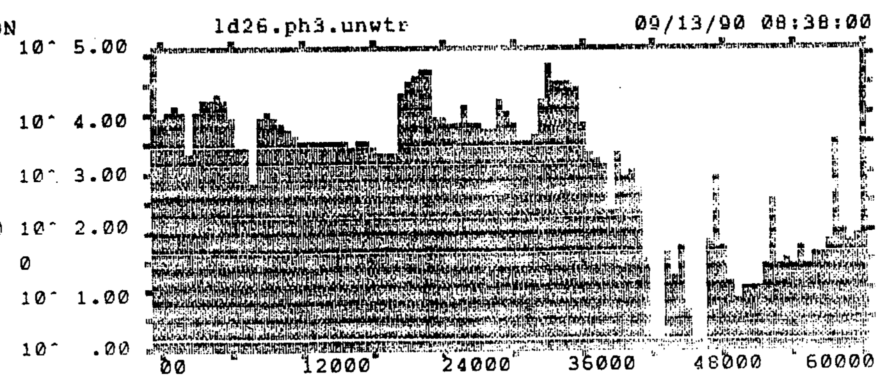
Events LTLF

C 1

Test Point = 500

D mand point = 0

GRAPH 1 OF 4

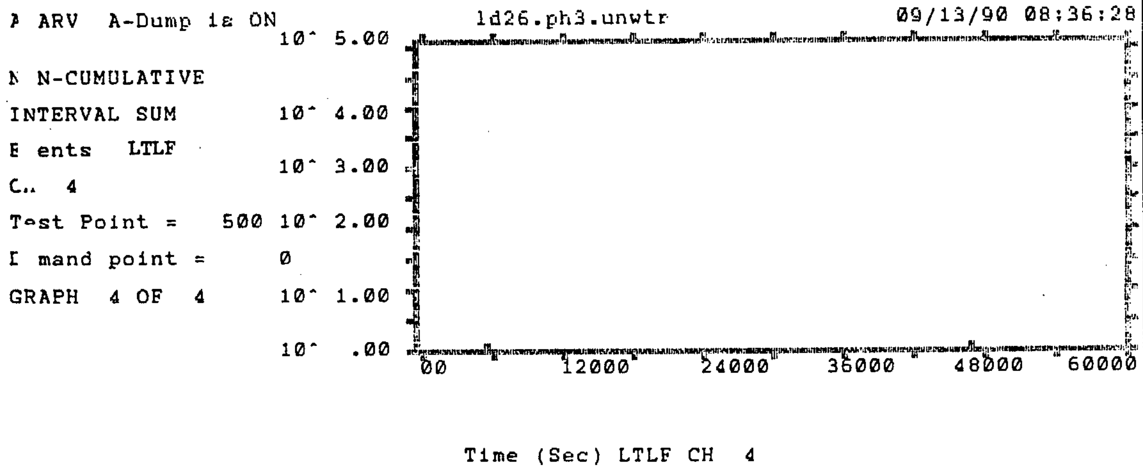


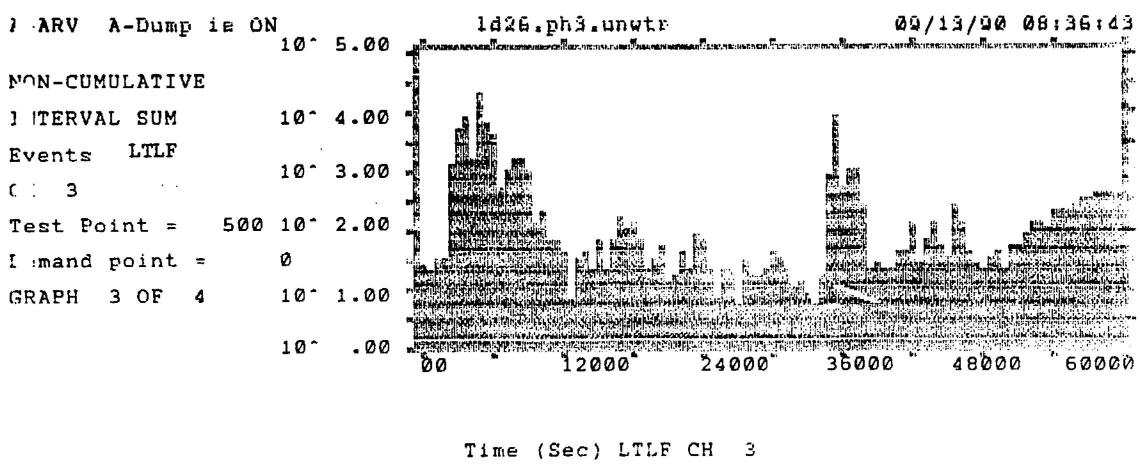
Time (Sec) LTLF CH 1

Record 7, TP 401-500

0920 Thurs. 07/19 - 0200 Fri. 07/20

B-31

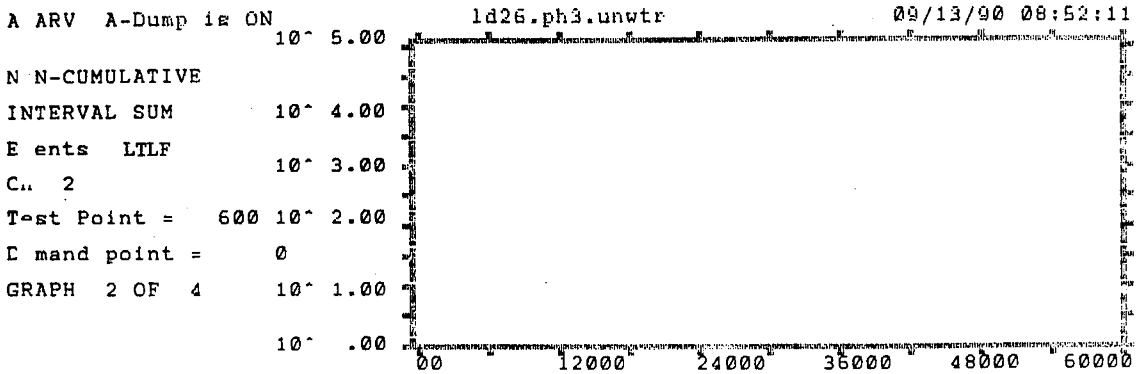




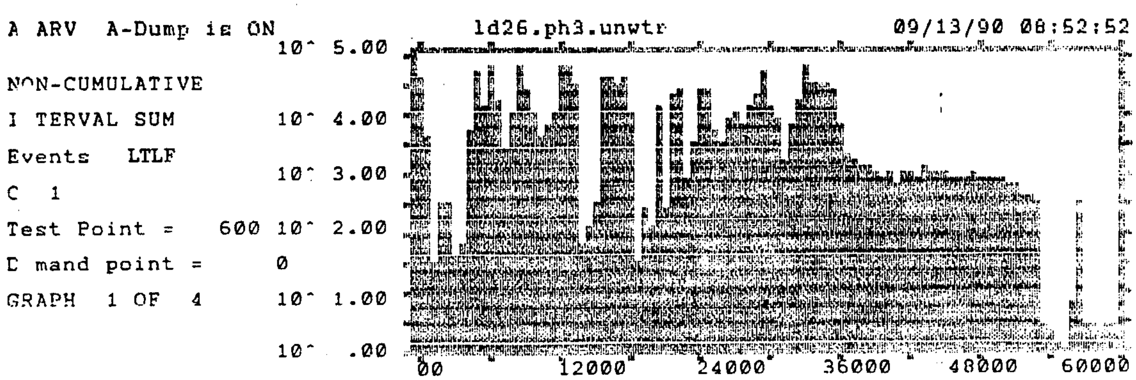
Record 7, TP 401-500

0920 Thurs. 07/19 - 0200 Fri. 07/20

B-32



Time (Sec) LTLF CH 2



Time (Sec) LTLF CH 1

Record 7, TP 501-600

0200 Fri. 07/20 - 1840 Fri. 7/20

B-33

A ARV A-Dump is ON

N N-CUMULATIVE

INTERVAL SUM

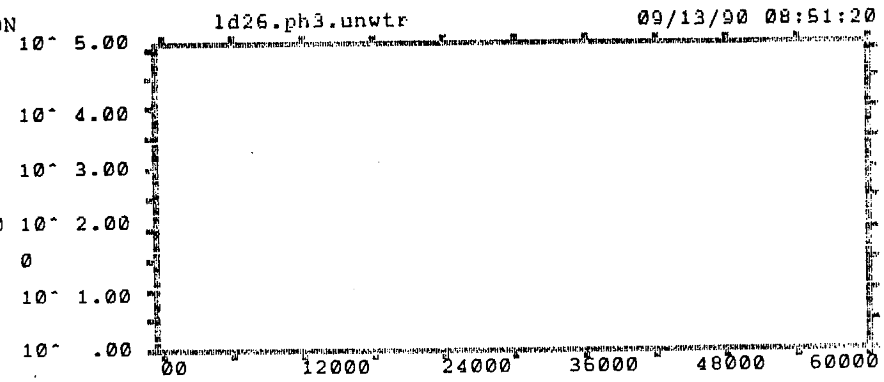
E ents LTLF

C. 4

T st Point = 600

D mand point = 0

GRAPH 4 OF 4



Time (Sec) LTLF CH 4

A ARV A-Dump is ON

N N-CUMULATIVE

I TERVAL SUM

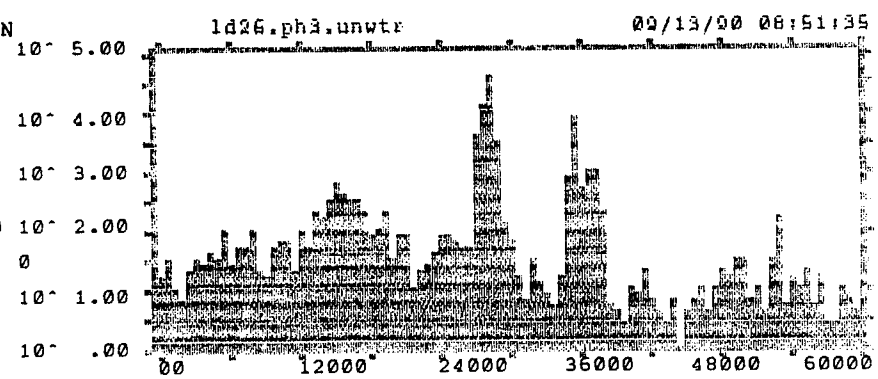
Events LTLF

C 3

Test Point = 600

D mand point = 0

GRAPH 3 OF 4



Time (Sec) LTLF CH 3

Record 7, TP 501-600

0200 Fri. 07/20 - 1840 Fri. 7/20

B-34

A ARV A-Dump is ON

N N-CUMULATIVE

INTERVAL SUM

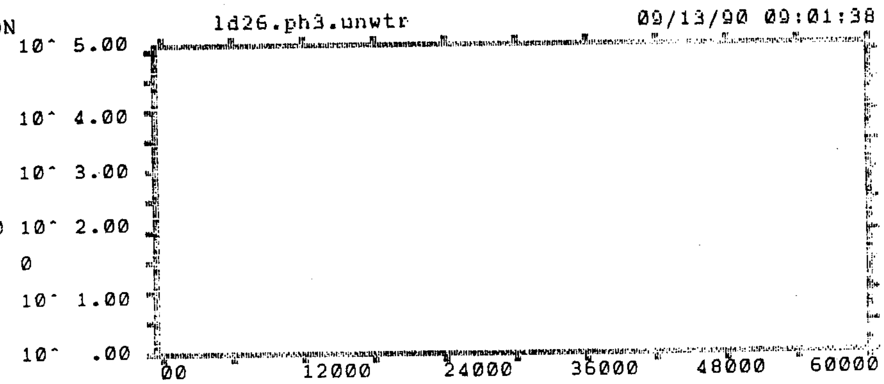
E ents LTLF

Cn 2

T-st Point = 700

I :mand point = 0

GRAPH 2 OF 4



Time (Sec) LTLF CH 2

ARV A-Dump is ON

NON-CUMULATIVE

I ITERVAL SUM

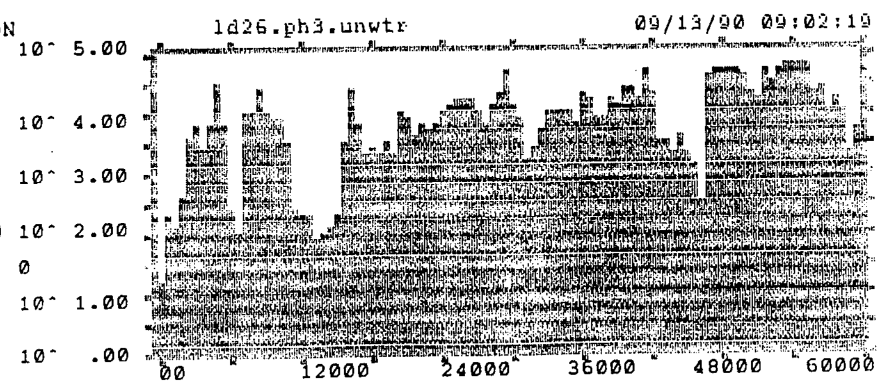
Events LTLF

C . 1

Test Point = 700

I mand point = 0

GRAPH 1 OF 4



Time (Sec) LTLF CH 1

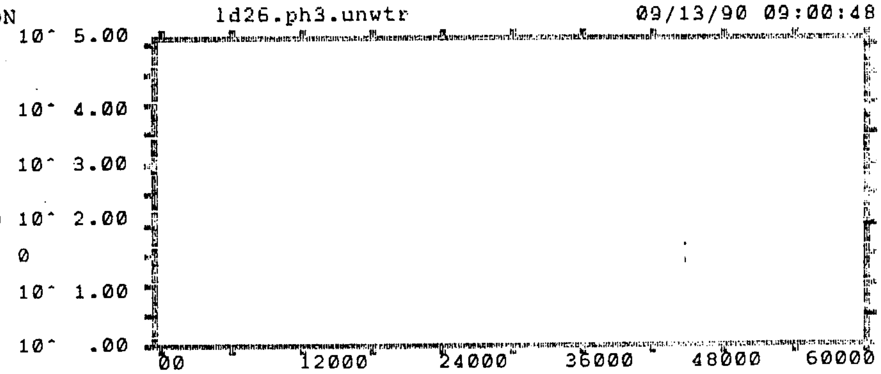
Record 7, TP 601-700

1840 Fri. 07/20 - 1120 Sat. 07/21

B-35

A ARV A-Dump is ON   1d26.ph3.unwtr   09/13/90 09:00:48

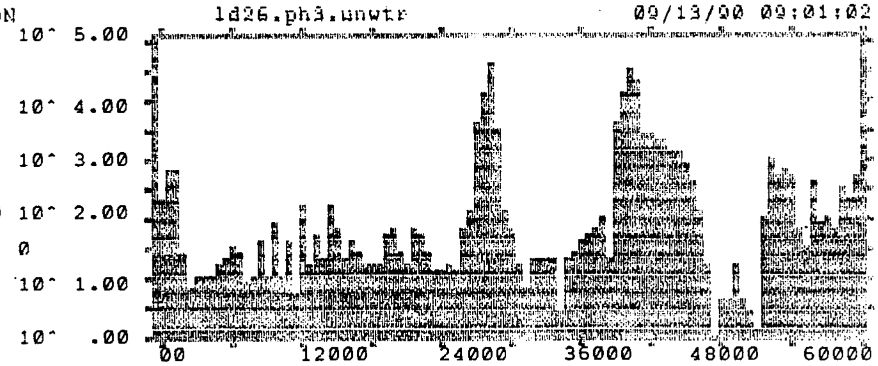
N N-CUMULATIVE
INTERVAL SUM
E ents LTLF
Cn 4
T-st Point = 700
D mand point = 0
GRAPH 4 OF 4



Time (Sec) LTLF CH 4

A ARV A-Dump is ON   1d26.ph3.unwtr   09/13/90 09:01:02

NON-CUMULATIVE
I TERVAL SUM
Events LTLF
C 3
Test Point = 700
D mand point = 0
GRAPH 3 OF 4

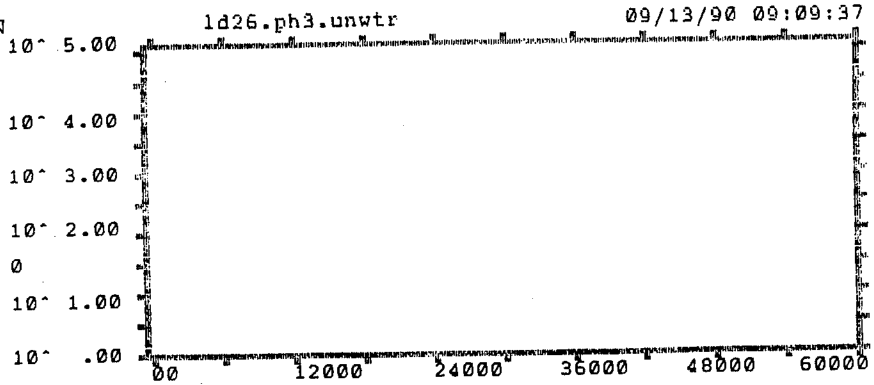


Time (Sec) LTLF CH 3

Record 7, TP 601-700
1840 Fri. 07/20 - 1120 Sat. 07/21

A ARV A-Dump is ON 1d26.ph3.unwtr 09/13/90 09:09:37

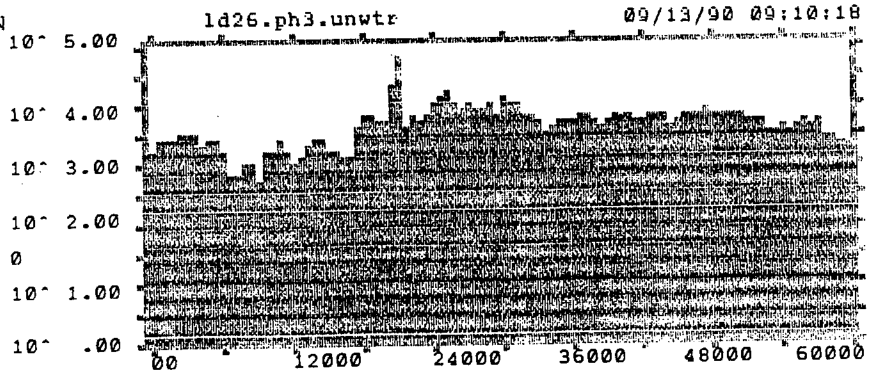
N N-CUMULATIVE
INTERVAL SUM
E ents LTLF
Cn 2
T-st Point = 800
D mand point = 0
GRAPH 2 OF 4



Time (Sec) LTLF CH 2

A· ARV A-Dump is ON 1d26.ph3.unwtr 09/13/90 09:10:18

NON-CUMULATIVE
INTERVAL SUM
Events LTLF
CI 1
Test Point = 800
De and point = 0
GRAPH 1 OF 4



Time (Sec) LTLF CH 1

Record 7, TP 701-800

1120 Sat. 07/21 - 0400 Sun. 07/22

B-37

Ⱦ ARV A-Dump is ON

N N-CUMULATIVE

INTERVAL SUM

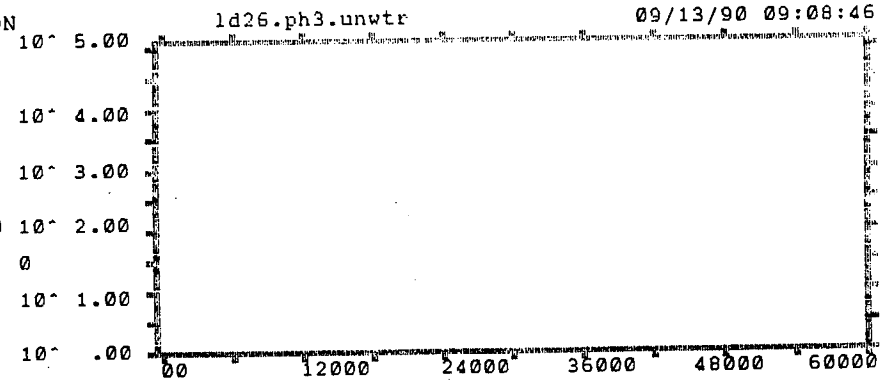
E ents LTLF

Cn 4

T st Point = 800

I mand point = 0

GRAPH 4 OF 4



Time (Sec) LTLF CH 4

Ⱦ ARV A-Dump is ON

N^N-CUMULATIVE

I TERVAL SUM

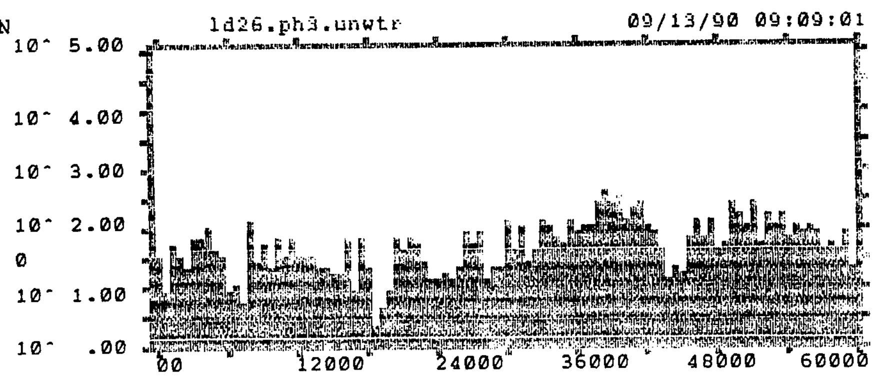
Events LTLF

C 3

Test Point = 800

I mand point = 0

GRAPH 3 OF 4



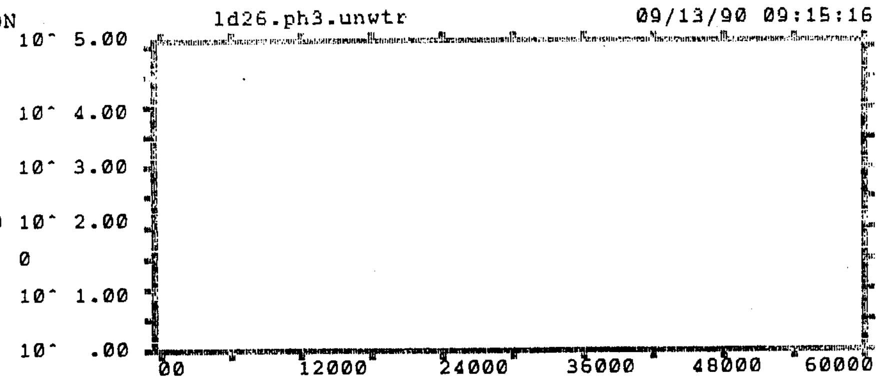
Time (Sec) LTLF CH 3

Record 7, TP 701-800

1120 Sat. 07/21 - 0400 Sun. 07/22

A ARV A-Dump is ON

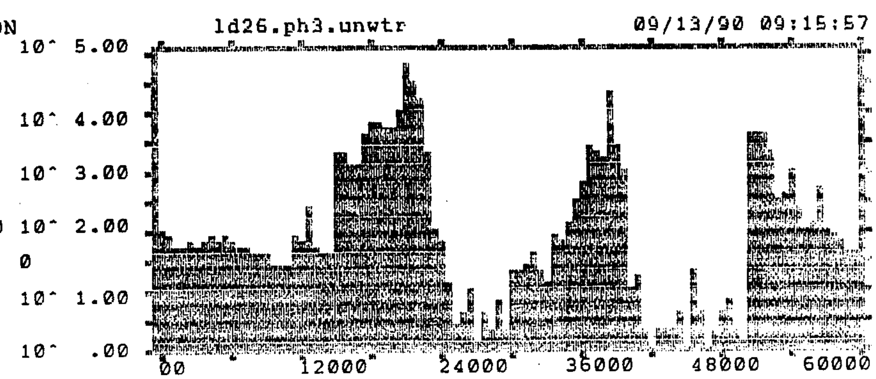
N N-CUMULATIVE
INTERVAL SUM
E ents LTLF
C. 2
T^st Point = 900
[mand point = 0
GRAPH 2 OF 4



Time (Sec) LTLF CH 2

? ARV A-Dump is ON

N^N-CUMULATIVE
I TERVAL SUM
Events LTLF
C 1
Test Point = 900
[mand point = 0
GRAPH 1 OF 4



Time (Sec) LTLF CH 1

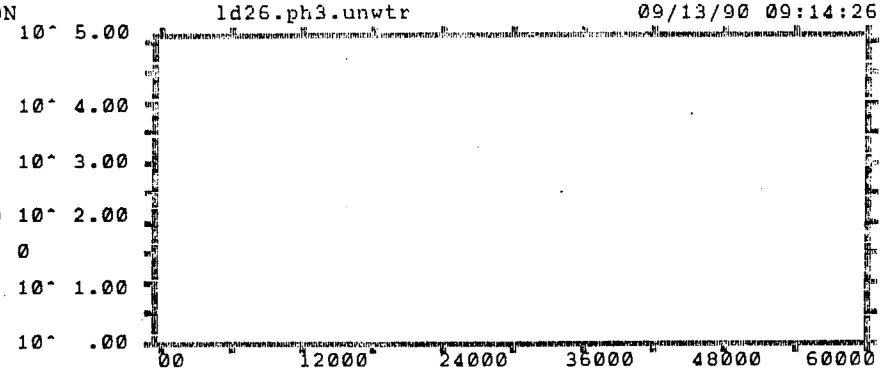
Record 7, TP 801-900

0400 Sun. 07/22 - 2040 Sun. 07/22

B-39

A ARV A-Dump is ON 1d26.ph3.unwtr 09/13/90 09:14:26

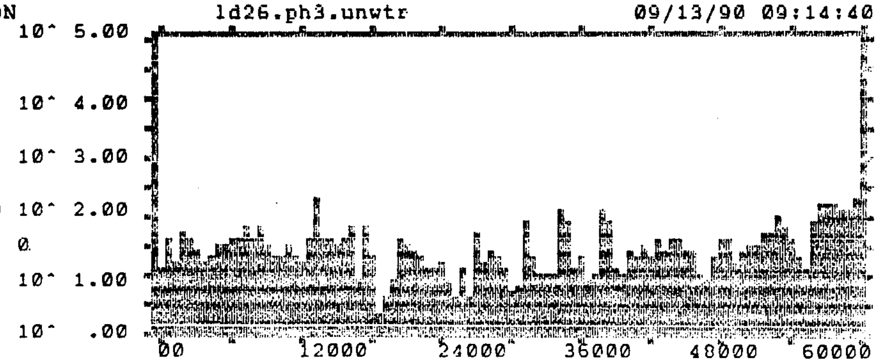
N N-CUMULATIVE
INTERVAL SUM
E ents LTLF
Cn 4
T-st Point = 900
D mand point = 0
GRAPH 4 OF 4



Time (Sec) LTLF CH 4

NOARV A-Dump is ON 1d26.ph3.unwtr 09/13/90 09:14:40

N N-CUMULATIVE
I TERVAL SUM
Events LTLF
C 3
Test Point = 900
D mand point = 0
GRAPH 3 OF 4



Time (Sec) LTLF CH 3

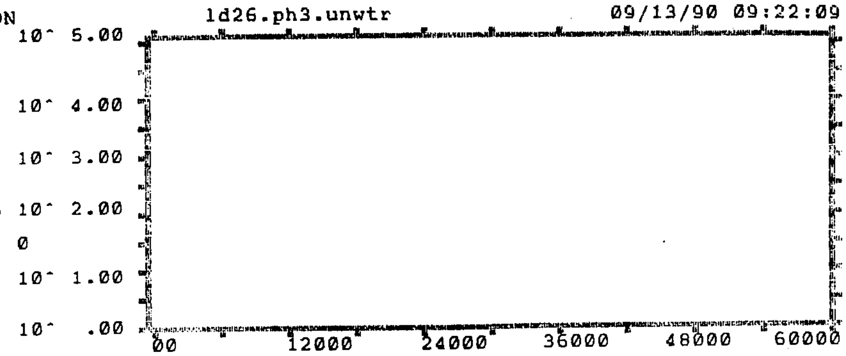
Record 7, TP 801-900

0400 Sun. 07/22 - 2040 Sun. 07/22

A ARV A-Dump is ON

1d26.ph3.unwtr 09/13/90 09:22:09

N N-CUMULATIVE
INTERVAL SUM
E ents LTLF
C. 2
T-st Point = 966
D mand point = 0
GRAPH 2 OF 4

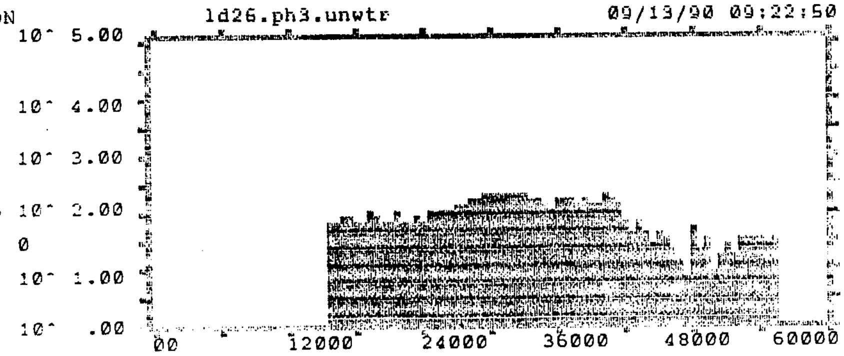


Time (Sec) LTLF CH 2

A ARV A-Dump is ON

1d26.ph3.unwtr 09/13/90 09:22:50

NON-CUMULATIVE
I TERVAL SUM
Events LTLF
C 1
Test Point = 966
D mand point = 0
GRAPH 1 OF 4



Time (Sec) LTLF CH 1

Record 7, TP 901-966

2040 Sun. 07/22 - 0740 Mon. 07/23

B-41

A ARV A-Dump is ON

N N-CUMULATIVE

INTERVAL SUM

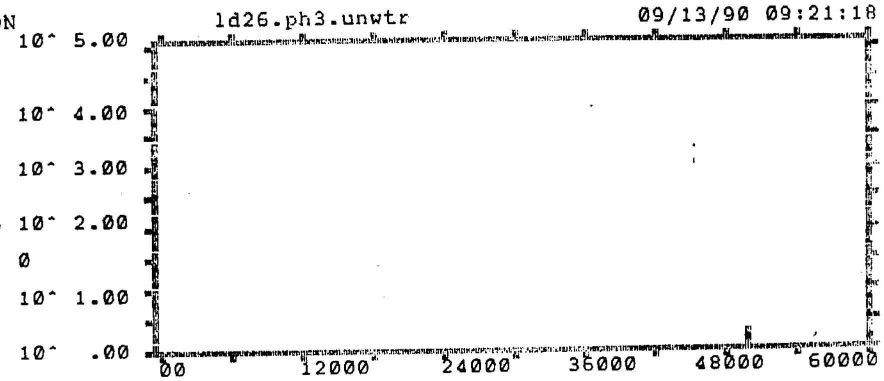
E ents LTLF

C.. 4

Test Point = 966

D mand point = 0

GRAPH 4 OF 4



Time (Sec) LTLF CH 4

A ARV A-Dump is ON

NON-CUMULATIVE

I TERVAL SUM

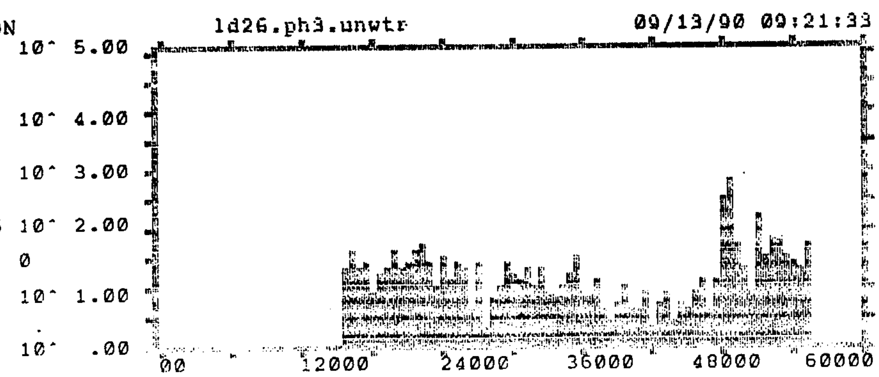
Events LTLF

C 3

Test Point = 966

D mand point = 0

GRAPH 3 OF 4



Time (Sec) LTLF CH 3

Record 7, TP 9-1-966

2040 Sun. 07/22 - 0740 Mon. 07/23

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Contract No.
DACW39-91-C-0005

6. AUTHOR(S)
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12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

A research program was conducted to develop a cofferdam distress warning system and monitor the acoustic emissions generated by the third-phase cofferdam of the Melvin Price Lock and Dam. The purpose of this study was to extend existing understanding of acoustic emission (AE) within large sheet-pile cell structures to the design, configuration, and operation of a cofferdam Distress Warning System (DWS) capable of automatic operation for an extended period and to correlate the acoustic emissions with the forces acting on the cofferdam.

14. SUBJECT TERMS

Acoustic emission	Distress warning system
Cofferdam	Field tests

15. NUMBER OF PAGES
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16. PRICE CODE

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